Exploring Construction Safety and Control Measures through Electrical Fatalities

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ABSTRACT

Globally, construction is considered a hazardous industry with a disproportionate amount of fatal and non-fatal injuries as compared to other industries. Electrocution is named as one of the "fatal four" causes for construction injuries by the Occupational Safety and Health Administration (OSHA). In the United States, an average of 47.9% electrical fatalities occurred in the construction industry from 2003 to 2012, according to the U.S. Department of Labor. These fatalities include both electrical workers and non-electrical workers. Such a disproportionate rate suggests a need of research to improve construction safety and reduce injuries due to electrocution. However, there is a lack of understanding of causation mechanisms surrounding fatal accidents by electrocution using a systems approach; and there is a disconnection between the mechanism of fatal electrocution accidents and the associated control measures, which may lead to less effective prevention in construction.

This dissertation has three objectives, including: (a) establishing a sociotechnical system model that reflects the electrocution occurrence in the U.S. construction industry and identify the associations among its internal subsystems; (b) determining specific electrocution patterns and associated mechanism constraints; and (c) examining hierarchy of control (HOC) measures and determining their appropriateness.

Findings from his research include: (a) the identification of three system patterns of electrocution in construction work systems and the associations between personnel, technological, organizational/managerial subsystems, and the internal and external environment for each of the three patterns, using a macroergonomics framework; (b) the identification of five features of work, and map out their decision-making chains, critical

decision-making points and constraints, as an interpretation of electrocution mechanisms in the workplace; and (c) revealing that behavioral controls remain prevalent in electrical hazard mitigation even though the knowledge of construction safety and health has increased in the past decades, and that the effectiveness of controls is not statistically different by construction type nor occupation.

Based on these findings, the research also suggests corresponding mitigation recommendations that construction managers shall strictly follow HOC rules by giving priority to higher level of controls and upgrading the industry's prevention strategy by introducing more technological innovations and encouraging prevention through design (PtD) strategies.

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INTRODUCTION

1.1 BACKGROUND

1.1.1 Electrocution in U.S. Construction

Internationally, construction is considered a hazardous industry with a disproportionate amount of fatal and non-fatal accidents for its workers as compared to other industries. Electrocution is among the “fatal four” in the US construction industry, according to the Occupational Safety and Health Administration (OSHA). Workers in the US construction encounter the highest risk from electrical injuries compared to any other industry. For example, 39.7% of the 163 electrical fatalities in 2011 are construction-related (BLS 2013), which means that approximately two in five nationwide electrical deaths occurred in the construction sector. Such a rate necessitates research into improving safety systems and reducing fatalities for this type of work and industrial sector.

1.1.2 Electrical Hazard and Fatalities

For decades, injuries due to electrocution continue to be a serious problem that has impacted the United States construction industry. Contact with electrical current was ranked as the fourth leading cause of death in construction in 2005 (CPWR 2008), after falls to a lower level, highway transportation injuries, and struck-by objects and equipment (see Table 1-1). Electrocution resulted in 916 deaths within the construction industry between 2003 and 2011(US Bureau of Labor Statistics, 2013), leading to a mortality rate of 1.1 per 100,000 full-time workers (CPWR 2008).

Workers in the U.S. construction industry encounter the highest risk from electrical injuries compared to any other industrial sector. Records of fatal work injuries from the Census of Fatal Occupational Injuries (CFOI), conducted by the Bureau of Labor Statistics (BLS 2013) of the U.S. Department of Labor illustrates that, on average, electrical fatalities in construction industry accounted for 47.9% of electrocutions from 2003 to 2012 (see Figure 1-1). These fatalities include both electrical workers and non-electrical workers. Typically, electrical workers include utility line installers and repairers, and electricians; while non-electrical workers include construction laborers, roofers, masons, and equipment operators.

Table 1-1. Top-ranked accidental causes leading to deaths in U.S. construction, 2005.

Accidental Causes	Count	Pct.
Fall to a lower level	384	32.2%
Highway transportation injuries	154	12.9%
Stuck by objects and equipment	130	10.9%
Contact w. electrical current	107	9.0%
Pedestrian-vehicular accident	97	8.1%
Crushed in collapsing materials	59	4.9%
Non-highway accident	53	4.4%
Compressed by equip. or object	52	4.4%
Exposure to caustic, noxious or allergenic substances	35	2.9%
Fires	27	2.3%
Other miscellaneous	94	7.9%
Total	1,192	100%

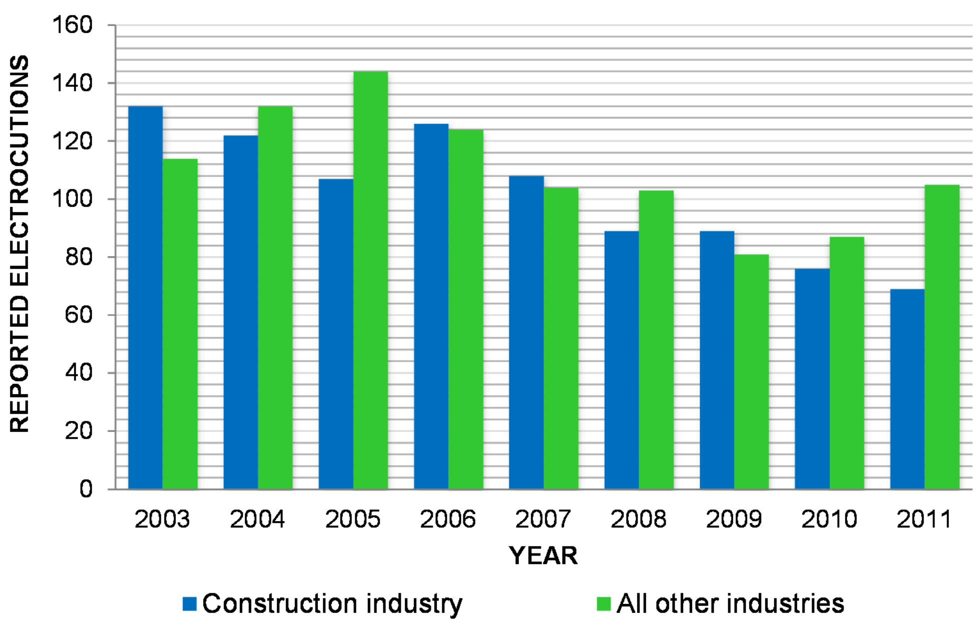


Figure 1-1. Electrocutions in construction industry vs. all other industries, 2003-2011.

Data source: US Bureau of Labor Statistics (2013)

1.1.3 Losses due to Electrical Injuries

Losses due to electrical injuries are not only in financial expenses but also physical and social trauma. Most accidents involving electric shocks are traumatic and cause severe tissue damage or death (Zhao, Lucas, & Thabet, 2009). Electrical injuries led to mortality rates as high as 15%, which resulted in roughly 1,000 deaths in the United States every year (Lee & Dougherty, 2003).

The average cost due to electrocution is $948,844 per case, which ranks as the highest per-fatal-case cost in construction (NIOSH 2006). Also, electrical injuries rank as the 2nd highest per-nonfatal-case cost in private industry, costing approximate $86,829 per case (Waehrer, Dong, Miller, Haile, & Men, 2007). On average, a nonfatal-case loss in construction is $42,093, accounting for less than a half of electrical injury losses. These costs include direct medical costs, indirect losses in wage and household productivity, as well as an estimate of the quality of life costs due to injury. These total costs in 2002 were estimated as 38.97 million (2002 dollar) by Waehrer et al. (2007). In comparison, the number one leading cause for construction injuries, i.e. falls to a lower level, leads to $58,019 per-nonfatal-case cost, which accounts for only 66.8% of that from electrical injuries.

1.1.4 Electrocution Rate in Construction

Electrocution rate is a measure of the number of deaths due to electrocution in a population in a given time period. Electrocution rate is typically expressed in units of deaths per million employees per year. Numbers of electrocutions and employees are two important aspects that impact electrocution rates.

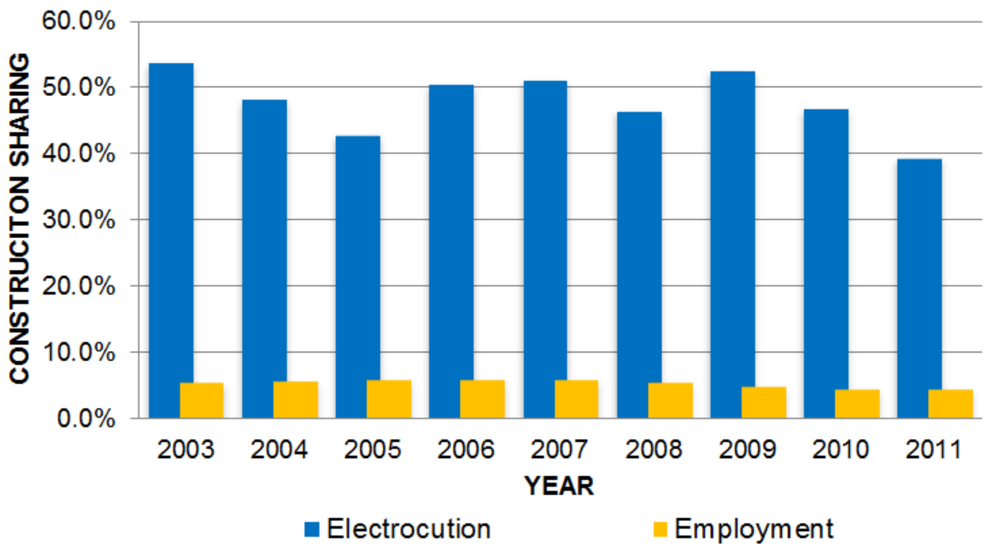


Figure 1-2. Construction's share in electrocution and employment.

Data source: Zhao, Thabet, McCoy, & Kleiner (2014).

The large electrocution share and smaller employment share in construction results in a relatively high electrocution rate. As shown in Figure 1-2, between 2003 and 2011, the construction sector encountered 47.80% of the fatal electrical injuries while hired approximate 5.05% of the entire U.S. employees (BLS 2012). In 2011 the electrocution rate for U.S. construction was 12.2 per one million full-time construction workers while it was 1.3 per one million full-time workers across all industries. Electrocution rate in construction is as much as 9.4 times of the average rate across industry. Echoing back to the years between 1992 and 2002, the electrocution rate for construction was still five times that for all industry levels (Cawley & Homce, 2008).

1.1.5 Surface Causes

Existing studies have calculated surface-based causes of electrocution in U.S. construction using statistical methods. From 2003 to 2005, the highest rates of death from electrocution existed among electrical power installers and repairers and earth drillers (Center for Construction Research and Training [CPWR], 2008). Construction occupations having the highest average electrocutions per year were electricians, construction laborers, supervisors/managers, electrical power installers and repairers. For 2003-2006, only 26% of electrical deaths were electricians, while the rest were associated with other trades within the construction industry (Janicak, 2008).

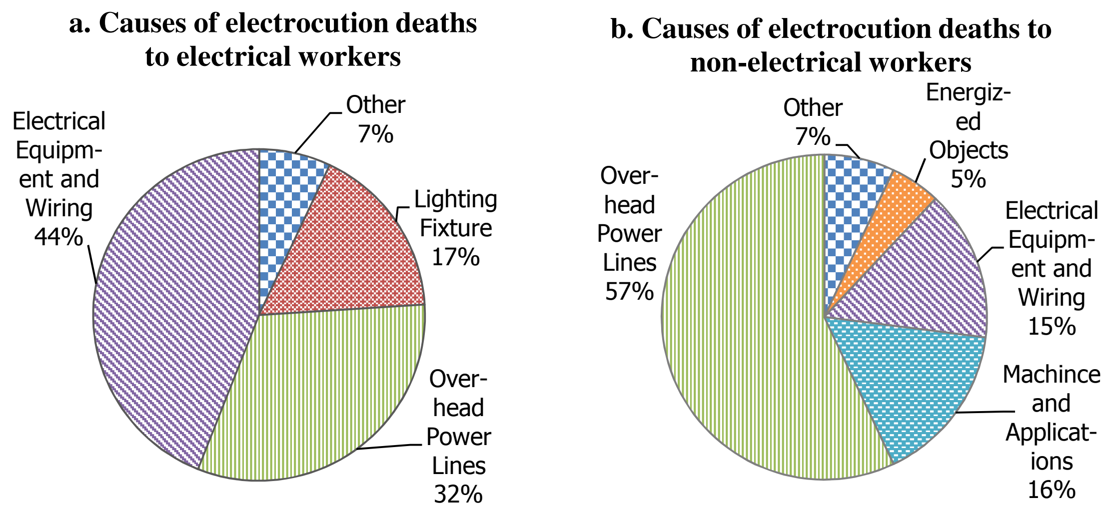


Figure 1-3. Electrocution deaths among workers in construction, 2003-2005.

Data source: Center for Construction Research and Training [CPWR] (2008).

Surface-based causes of electrocution in construction differ between electrical workers and non-electrical workers, though, illustrating the differences in mechanisms for these accidents. Between 2003 and 2005, the main cause of electrocution of electrical workers (consisting of electricians, electrical power installers and repairers, their apprentices and helpers doing electrical work, and their supervisors) was contact with energized, or "live", equipment and wiring. Conversely, the secondary cause of electrical workers' deaths was contact with overhead power lines (Figure 1-3a). The main cause of electrocution of non-electrical workers was contact with overhead power lines and the secondary cause was by machinery and appliances with faulty electrical systems (Figure 1-3b). These non-electrical workers often were construction laborers, roofers, masons, and heavy construction equipment operators. Contact with overhead lines includes direct contact by the person (accounting for approximately 20% of the incidences) and indirect contact such as energized objects transferring the current and causing electrocution.

1.2 Problem Statement

Existing research has attempted to provide insight into electrical fatalities in construction safety while gaps still exist, including:

Problem #1: *There is a lack of systematic understanding of causation mechanisms surrounding fatal accidents by electrocution.*

Statistical interpretations of surface causes are limited in their presentation of accidental mechanisms. The statistical data and related research is convincing to describe the status of the current safety situation. For example, the U.S. Bureau of Labor Statistics continues to collect data through the census of fatal occupational injuries (CFOI). The personnel approach, as a longstanding and widespread traditional viewpoint, focuses on the unsafe acts of workers at the sharp end (Reason, 2000). Workers are viewed as free agents capable of choosing safe or unsafe behaviors and should be responsible. The personnel approach viewpoint is often narrow and insufficient and thus, usually leads to unconvincing conclusions. For example, Ore and Casini (1996) used statistical methods to analyze electrical fatalities from 1980 to 1991 and concluded that workers most at risk of electrical injury are male, young, nonwhite, and electricians, structural metal workers, and laborers. They used the personnel approach and are not believed to be sufficient to identify the causation and present the accidental mechanisms.

Moreover, personnel approach emphasizes on the individual origins of unsafe actions while often overlooks the associations and interactions within the whole system. The present investigations on electrocutions are mostly based on the root cause analysis (RCA) models, failure mode and effects analysis (FMEA) or fault tree analysis (FTA) and therefore look chiefly at individual actions rather than on organizational issues (Garrett & Teizer, 2009). Human errors are separated from the contextual system and, as a result, the relationships between personnel and hazards are omitted. In fact, an error might be seen as an action or decision that results in one or more unintended negative outcomes (Strauch, 2002). Finally, the nature of errors, the interpretation and the determination of error significance are largely contextual. What ultimately differentiates errors is their contexts and the relative severity of their consequences. Thus, a systems perspective covering electrical hazards, human errors and their contexts and the relative severity of their consequences is necessary as a basis for probing into electrical safety issues. However, there are not studies which use a systems approach to address electrical fatality in the U.S. construction industry.

Problem #2: *There is a disconnection between the mechanism of fatal electrocution accidents and the associated control measures, which may lead to less effective prevention in construction.*

Current studies have rarely addressed accident prevention in a hierarchic perspective of electrical safety in U.S. construction. The lack of a hierarchy of control measures may result in disconnect between fatal accidents and prevention techniques and ultimately may lower the impact of controls.

Horizontally, control measures are not holistic and current prevention strategies rarely confine them to a specific set of circumstances. Prevention is usually determined based on the identification of processes that lead to errors. Different accident scenarios contain different accident consequences even if their causations are similar. Therefore it would not be appropriate to rate the importance of one control measure without putting it into a specific scenario to be considered (Woodcock, Drury, Smiley, & Ma, 2005). Thus prevention strategies should be explicitly identified based on a variety of fatal patterns.

Vertically**,** control measures are hierarchical and equal treatment does not lead always to effective prevention strategies. Hierarchical challenges include the stages of construction (from design to operation) in which the control is decided and implemented. Even pertaining to similar control measures, effectiveness may be different depending on the stage in which the decision is made. For vertical control measures, prevention means are hierarchical and the most appropriate preventions often result in the most effectiveness.

1.3 RESEARCH OBJECTIVES

This research aims to achieve following objectives:

Objective #1: *Establish a sociotechnical systems model that reflects the electrocution occurrence in the U.S. construction industry and identify the associations among its internal subsystems.*

Specific tasks include:

- Establishing a sociotechnical system model reflecting the electrocution occurrence in the U.S. construction industry based on Kleiner's systematic modeling methods.

- Measuring the sociotechnical factors that occur surrounding an electrocution occurrence using content analysis on the data from the NIOSH investigation reports on construction electrocution.
- Analyzing the associations among factors within each subsystem using mathematical methods such as latent class analysis (LCA) and correspondence analysis (MC).

Objective #1 is to establish a systems model that integrates data from construction electrocution reports and contribute to deeper understanding systemic prevention. The systems model includes personnel, technical and environmental subsystems (Kleiner, Smith-Jackson, Mills, O'Brien, & Haro, 2008). The model is expected to be created based on literature review, expert interviews and extracted data from fatality investigations (NIOSH FACE reports). After establishing a model, the study analyzes associations among each subsystem to reveal internal correlates to the system. Results from objective #1 may contribute to potential solutions for problem #1.

Objective #2: *Determine specific electrocution scenarios and associated mechanism constraints.*

Specific tasks include:

- Classifying typical electrocution scenarios using cluster analysis methods such as the Chi-squared Automatic Interaction Detection (CHAID).
- Identifying the decision-making chains in each classified patterns using function diagrams such as the box-and-arrow diagram (IDEF0).
- Diagnosing each decision making chain to determine the mechanisms and constraints in each electrocution pattern

Electrocution mechanisms are not holistic and cannot be comprehensively explored through discrete hazard and accident scenarios. Therefore, objective #2 aims to cluster typical electrocution scenarios through a scientific classification method and pattern analysis, highlighting systemic constraints to decision-making processes under aggregate and individual scenarios. Chi, Lin, and Ikhwan (2012) applied similar method in coding data for electrocutions to find a subset of predictors that might derive meaningful classifications or accident scenarios. The researcher- also constructed a series of flow diagrams to illustrate the flow of electricity traveling from electrical source to a human body. Similarly, this study aims to apply a similar methodology to U.S. electrocution data, which has not been addressed previously by existing research. Results from objective #2 may illustrate electrocution mechanisms (in terms of decision-making) in U.S. construction and may also contribute to potential solutions for both problem #1 and problem #2.

***Objective #3**: Examine hierarchy of control measures and determine appropriateness of action through an analysis of electrocution investigation recommendations.*

Specific tasks include:

- Examining the prevention recommendations from FACE reports to identify relationships and hierarchy among different control measures based on the NIOSH model of Hierarchy of Controls (HOC).
- Comparing the effectiveness of a variety of control measures using quantitative methods.
- Linking the effectiveness of control measures with their specific content by analyzing control measures using qualitative methods such as narrative text analysis (NTA).

Although fatality investigations provide a list of prevention recommendations, the effectiveness of recommended control has not been addressed. Objective #3 aims to analyze NIOSH recommended control measures to determine appropriate and effective prevention strategies. Kunadharaju, Smith, and DeJoy (2011) applied similar method to generalize key recommendations for preventions of firefighter deaths. The researchers not only described procedures used to derive key or sentinel recommendations but also disclosed the relationships of different recommendations and how similar recommendations were handled within and across investigations. This research extends similar methods to a hierarchy of controls and analysis of NIOSH recommendations for the U.S. construction electrocution. Results from Objective #3 may contribute to potential solution for problem #2.

1.4 LIMITATIONS AND ASSUMPTIONS

Some limitations exist in this work. One is the limited sample size, which might cause statistical error; however, the probability of error can be lowered through certain countermeasures. Another limitation is that the data used in this research, FACE reports, were human-compiled and might be subjective; however, its probability is constrained by the NIOSH investigator's professionalism and expertise.

This research has three basic assumptions. The first one is that all accidents are preventable. The second is that rather than single element (e.g., human), the sociotechnical system breakdowns provide an essential contribution to the electrocution occurrence. The third assumption is that, from a hierarchy of controls perspective, risk can be eliminated from the task through appropriate controls.

1.5 METHODOLOGY

1.5.1 Research Design Overview

The research framework primarily includes data collection, data analysis, and results compilation. From top to down, Figure 1-4 below illustrates the "*Research Path*" from identifying problems in construction safety to the results and implementation towards satisfying the objectives of this research in contributing to solving problems of the construction industry. The research results are compiled in a dissertation format, which is represented as the "*Dissertation Path*" at bottom of the research structure diagram (see Figure 1-4).

The data source used in this research is from the Fatality Assessment and Control Evaluation (FACE) program managed by the National Institute of Occupational Safety and Health (NIOSH) professional investigators (NIOSH, 2010). Specifically, construction electrocution reports from this data source are selected as data cases. These reports belong to secondary data. FACE reports provide descriptions on hundreds of fatal occupational injuries through investigating work situations and disseminate prevention strategies since 1982, and thus are recommended as a key occupational safety and health (OSH) data resource for construction surveillance information by the National Occupational Research Agenda (NORA 2008). This research on U.S. construction electrocution directly collects cases from the NIOSH FACE program website (NIOSH 2010).

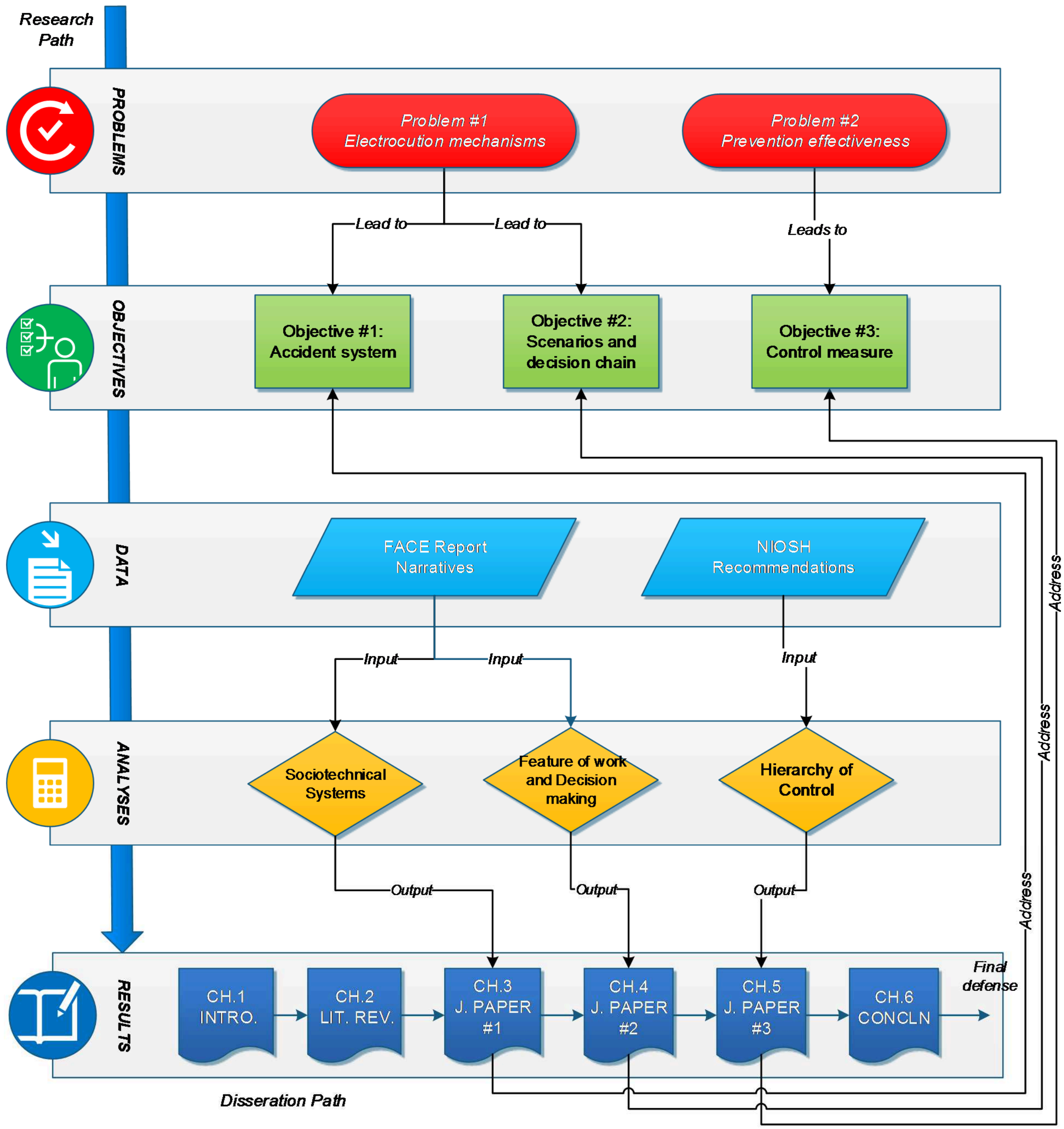


Figure 1-4. Research design and structure.

In general, the methodology used in this research is a combination of narrative text analysis and sociotechnical systems analysis. The literature has shown that narrative text analysis has widely utilized in OSH research, and thus is also applied in other research areas, for example, the public health and medicine (D'Souza, Smith, & Trifiletti, 2007; Farmakakis et al., 2007). Meanwhile, macroergonomic as well as sociotechnical system theory has been adopted in disciplines such as manufacturing, industrial engineering, or business management (Salmon, Cornelissen, & Trotter, 2012). However, lack of the combination is used in either construction sector or other disciplines. This research on construction electrocution may potentially exhibit how to integrate systems theory with text mining techniques, and may be scalable as a showcase for research in other disciplines.

1.5.2 Data Collection

The National Institute of Occupational Safety and Health (NIOSH) investigates fatal occupational injuries through its Fatality Assessment and Control Evaluation (FACE) program by identifying and investigating work situations at high risk for injury and then formulating and disseminating prevention strategies (NIOSH, 2010). FACE reports are a key occupational safety and health surveillance resource for surveillance information for construction mentioned by the National Occupational Research Agenda (NORA 2008). The program provides full text for hundreds of fatality investigation reports beginning in 1982. Compared to other NORA recommended resources, such as the Census of Fatal Occupational Injuries (CFOI), FACE reports offer more explicit case studies, detailed contexts and professional investigation conclusions instead of mere statistical numbers. Also, since 1982, FACE reports have a valid history of systematic and sufficient data for the study.

Therefore this work utilizes NIOSH FACE reports as the data source in this research. Particularly, to provide an historical perspective, FACE cases with the cause of electrocution in construction from 1989 to 2012 were selected. Fatality investigation reports can be indexed by two sub-programs: one is NIOSH In-house reports which are conducted by NIOSH; and the other is State-based reports which are conducted by NIOSH's cooperative state partners. Except for authors' voice, the two sub-programs are neither different in format nor overlapped in content. Also, FACE reports can be indexed by industry, fatality cause or populations. Construction is one category that could be indexed by industry and Electrocution is another category by fatality causes. Cases under the category of Electrocution are the collection of different types of electrical shocks and electrocution accidents that happened in real life. Consequently, overlapped cases under the categories "Construction" and "Electrocution" from both NOISH in-house reports and state-based reports are selected. In addition, the electrocution cases that happened in 2012 are the most recently posted in FACE program (see Appendix B).

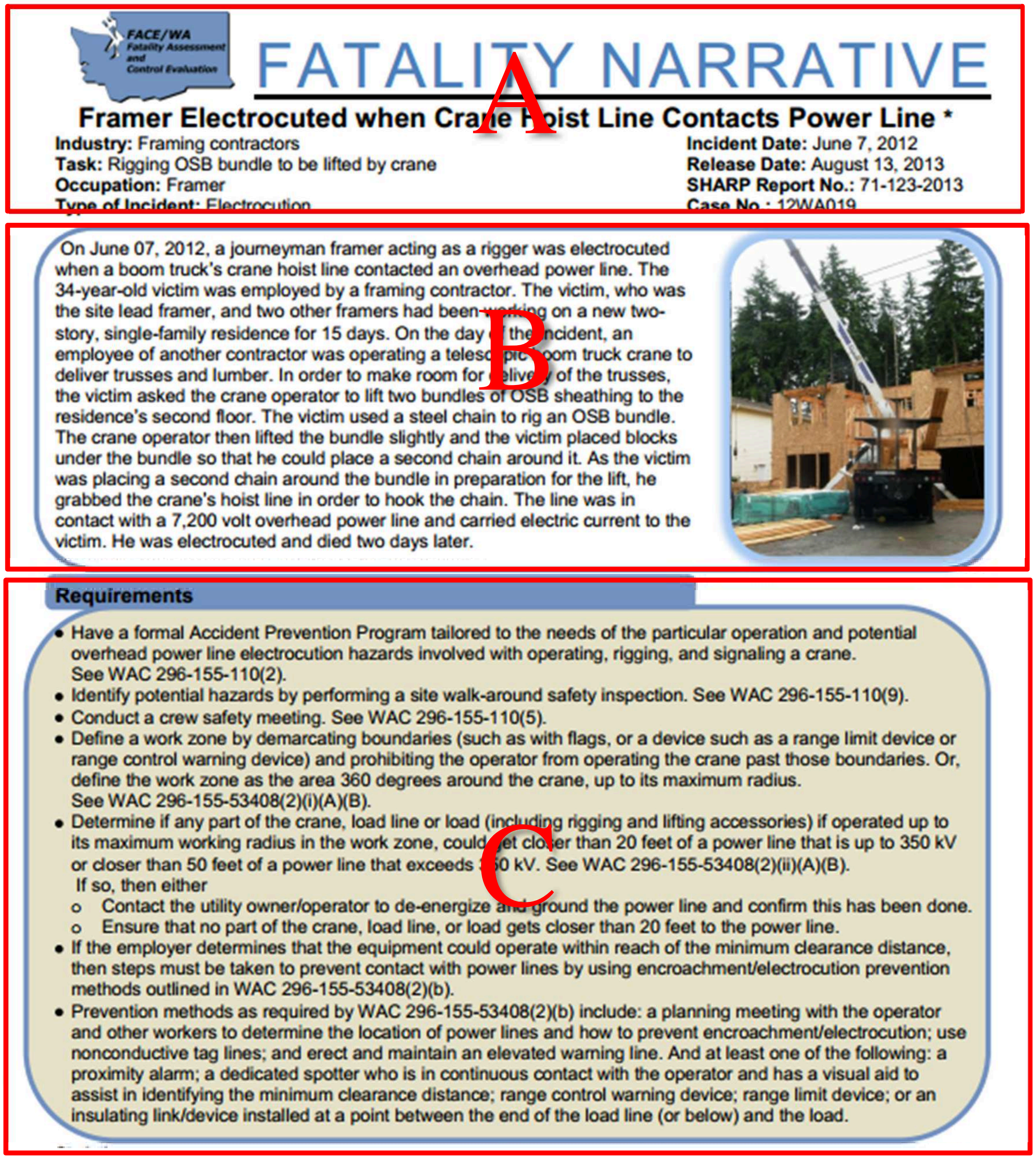
The study directly assembled case data from the NIOSH FACE program website (NIOSH 2010). As FACE does not includes a combined category of electrocutions in construction, a manual case sampling-out was conducted based on three basic criteria:

(a) the victim dies when at work;
(b) the cause of death, according to the death certificate, is electrocution; and
(c) the employer of victim belongs to the construction industry.

The definition of the construction industry complies with the North American Industry Classification System (NAICS) in which the construction sector is from code 230000 to 238990.

Figure 1-5 provides a typical example of a section of a FACE accident report, which is directly screen snapped from FACE website. From this figure, the report includes three major components:

A) incident brief summary;
B) incident process narrative (some with photo or sketch); and
C) prevention recommendations.



FACE/WA Fatality Assessment and Control Evaluation

FATALITY NARRATIVE

Framer Electrocuted when Crane Hoist Line Contacts Power Line *

Industry: Framing contractors
Task: Rigging OSB bundle to be lifted by crane
Occupation: Framer
Type of Incident: Electrocution

Incident Date: June 7, 2012
Release Date: August 13, 2013
SHARP Report No.: 71-123-2013
Case No.: 12WA019

On June 07, 2012, a journeyman framer acting as a rigger was electrocuted when a boom truck's crane hoist line contacted an overhead power line. The 34-year-old victim was employed by a framing contractor. The victim, who was the site lead framer, and two other framers had been working on a new two-story, single-family residence for 15 days. On the day of the incident, an employee of another contractor was operating a telescopic boom truck crane to deliver trusses and lumber. In order to make room for delivery of the trusses, the victim asked the crane operator to lift two bundles of OSB sheathing to the residence's second floor. The victim used a steel chain to rig an OSB bundle. The crane operator then lifted the bundle slightly and the victim placed blocks under the bundle so that he could place a second chain around it. As the victim was placing a second chain around the bundle in preparation for the lift, he grabbed the crane's hoist line in order to hook the chain. The line was in contact with a 7,200 volt overhead power line and carried electric current to the victim. He was electrocuted and died two days later.

Requirements

- Have a formal Accident Prevention Program tailored to the needs of the particular operation and potential overhead power line electrocution hazards involved with operating, rigging, and signaling a crane. See WAC 296-155-110(2).
- Identify potential hazards by performing a site walk-around safety inspection. See WAC 296-155-110(9).
- Conduct a crew safety meeting. See WAC 296-155-110(5).
- Define a work zone by demarcating boundaries (such as with flags, or a device such as a range limit device or range control warning device) and prohibiting the operator from operating the crane past those boundaries. Or, define the work zone as the area 360 degrees around the crane, up to its maximum radius. See WAC 296-155-53408(2)(i)(A)(B).
- Determine if any part of the crane, load line or load (including rigging and lifting accessories) if operated up to its maximum working radius in the work zone, could get closer than 20 feet of a power line that is up to 350 kV or closer than 50 feet of a power line that exceeds 350 kV. See WAC 296-155-53408(2)(ii)(A)(B).
  If so, then either
  - Contact the utility owner/operator to de-energize and ground the power line and confirm this has been done.
  - Ensure that no part of the crane, load line, or load gets closer than 20 feet to the power line.
- If the employer determines that the equipment could operate within reach of the minimum clearance distance, then steps must be taken to prevent contact with power lines by using encroachment/electrocution prevention methods outlined in WAC 296-155-53408(2)(b).
- Prevention methods as required by WAC 296-155-53408(2)(b) include: a planning meeting with the operator and other workers to determine the location of power lines and how to prevent encroachment/electrocution; use nonconductive tag lines; and erect and maintain an elevated warning line. And at least one of the following: a proximity alarm; a dedicated spotter who is in continuous contact with the operator and has a visual aid to assist in identifying the minimum clearance distance; range control warning device; range limit device; or an insulating link/device installed at a point between the end of the load line (or below) and the load.

Figure 1-5. FACE report example.

Neither the primary data source nor the secondary data source provides 100 percent accurate and reliable information and the quality of collected data is dependent upon a number of other factors (Kumar, 2005). The FACE reports are secondary data, and thus some important aspects have been considered to constrain disadvantages and to ensure the data reliability and validity. These considerations aspects as well as responses are listed in Table 1-2. As a result, the FACE reports, as the secondary data source, may contribute to the study objectives with advantages of secondary data, and may also work appropriately with respective treatments that limit disadvantages of secondary data.

Table 1-2. Considerations for using secondary data

Consideration	Description	Response
`Familiarity	Researcher needs to be familiar with secondary data set, including how the data was collected, what the response categories are for each question, whether or not clusters or stratification needs to be accounted for, who the population of study was, etc.	NIOSH provides detailed introduction of FACE program. Also, researcher keeps contacting with FACE department (e.g., MA FACE, KY FACE)
Suitableness	Secondary data may not answer the researcher's specific research questions or contain specific information that the researcher would like to have. Or it may not have been collected in the geographic region desired, in the years desired, or the specific population that the researcher is interested in studying.	FACE reports provide good understanding and electrocution investigation throughout the country. The data fit researcher's objective.
Control	Since the researcher did not collect the data, he or she has no control over what is contained in the data set.	The researcher will tease out information to find what This research is looking for.
Document	Limited existing variables in secondary data may lower the quality of documentation. The variables in secondary data may be defined or categorized differently than the researcher would have chosen.	Since FACE reports are narrative (text) data, the problem in variable does not exist.
Quality	Secondary data collectors may not meet the required specialized skills that data may potentially lack depth.	The professionalism of NIOSH investigators is worthy of trust. It is recommended by NORA.

In terms of analysis capability, this dataset primarily includes qualitative data but from which quantitative information may be extracted. Case size, which is expected at more than 140, statistically provides adequate coverage of the market in question although not all fatalities are included in the FACE investigations. On the other hand, the proposed methods of internal association analyses may rarely be impacted by the case size. As a result, this data source is confidently eligible to obtain proposed research objectives. Compared to only statistical numbers, the FACE data source provides more explicit accidental narratives, detailed contexts and professional investigation conclusions and all of which are critical to build the accident framework.

Therefore, the NIOSH FACE reports are an eligible data source for this study in both historical and systematic perspectives.

1.5.3 Major Research Techniques

According to pervious section, FACE reports are text-based data without distinct variables. This characteristics of FACE reports as narrative text data determine that the primary responding research foundation is narrative text analysis.

Figure 1-6 illustrates the framework between data collection and research analysis in this research. This methodological framework includes qualitative analysis and quantitative analysis and is framed under sociotechnical system theory (Hendrick & Kleiner, 2002), which provides theoretical background to narrative review and text searching, and may help to detect bilateral misfits within the current U.S. construction electrocution work environment (Haro & Kleiner, 2008; Salmon et al., 2012) towards occupational safety and health issue.

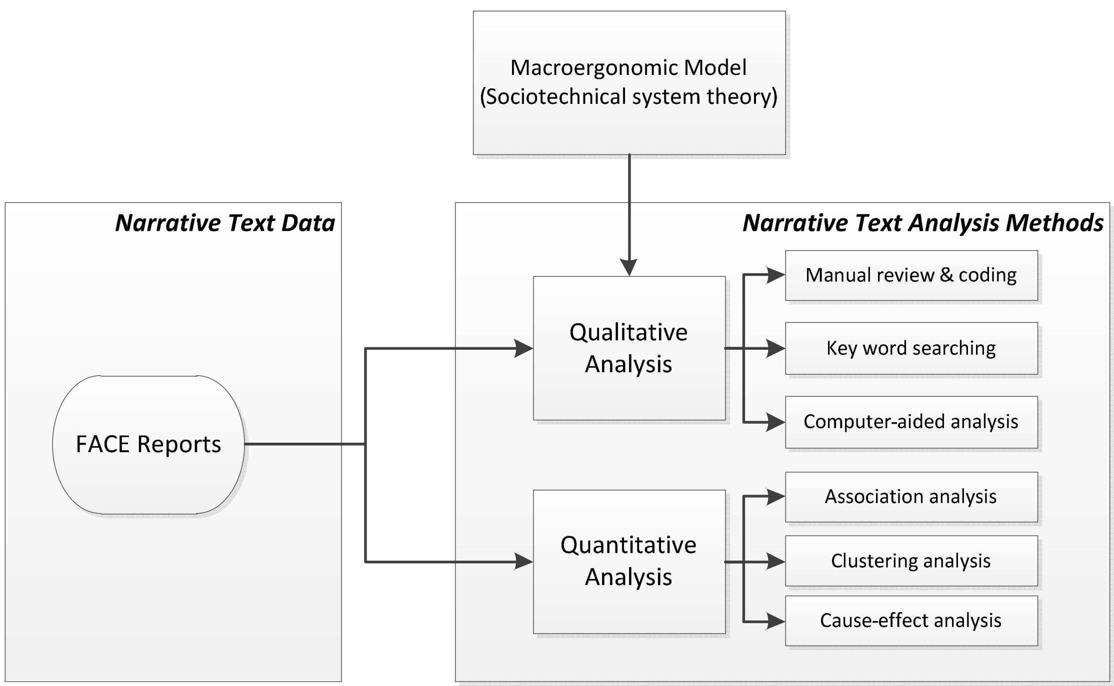


Figure 1-6. Framework of data and analyses.

Based on the assumption of the system model that safety problem is resulted from bilateral misfit between two system elements, the quantitative analysis shall concentrate on the assessment on the relationship between factors (Conte, Rubio, García, & Cano, 2011; Lu, Mei, Wang, & Zhang, 2012; Sourial et al., 2010). Therefore, analysis techniques such as association analysis and correspondence analysis may be applied. In addition, qualitative methods such as text analysis may also be applied as supplement to verify quantitative analysis results (Hobbs & Kanki, 2008).

Specifically, major analysis models and techniques are listed as follows:

- Qualitative analyses:
  (a) Narrative text analysis (NTA)
  (b) Macroergonomic model (MM)
  (c) Retrospective content analysis (RCA)
  (d) Decision-tree mapping, such as IDEF0 diagram
- Quantitative techniques:
  (a) Frequency Analysis (FA)
  (b) Association analysis (AA)
  (c) Correspondence analysis (CA)
  (d) Latent Class analysis (LCA)
  (e) Chi-squared Automatic Interaction Detector (CHAID)

The coming section will describe some major models and analysis techniques that are applied in this research, and their utilization towards certain specific research objective.

Narrative Text Analysis (NTA)

The narrative text analysis is a qualitative analysis technique that is to extract and explore useful hidden information through analytical methods (e.g., natural language processing) turning text into data. Specific text analysis methods include information retrieval, lexical analysis to study frequency distributions, pattern recognition, tagging/annotation, information extraction, text mining, visualization and predictive analytics. NTA has been accepted and applicable in the proposed research field. Specifically, this research applies NTA technique on the FACE investigation reports for OSH research in AEC industry.

This technique is adopted as a fundamental method throughout entire research for reaching objective #1, objective #2 and objective #3.

Macroergonomic Model

Macroergonomic Modeling (MM) is a technique, devised from Macroergonomic theory, for determining the relations and interactions among personnel sub-system, technological subsystem and the external environments (Hendrick & Kleiner, 2002; Kleiner, 2006). In contrary with ergonomics, MM provides a systematic perspective within which all problem elements are linked, related and reacted instead of being isolated in a social-technical system. In this core, deeper relationship and causation might be uncovered by conducting MM.

Therefore, using sociotechnical theory (e.g., MAS and MEAD), the author preliminarily develops a construction accident model – Tetrahedron Model (see Figure 1-7) and views accident causations as the misfits within OSH work system. This system model includes four major elements: personnel, technology, organization and environment. This model includes two fundamental assumptions, which are as follows:

- All elements interact - any change in one may affect other elements;
- Any bilateral misfit between any two elements may result in safety problem.

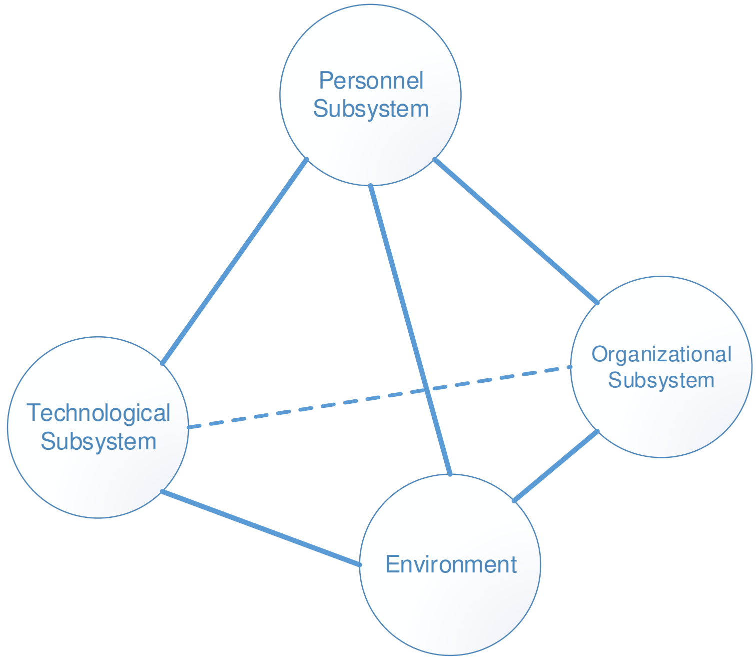


Figure 1-7. Tetrahedron model for construction accidents.

Macroergonomic theory (e.g., MAS, MEAN) is used to detect bilateral misfits within electrocution system. For example, possible problems in these system elements may be: worker lacks skills/knowledge base; employees do not agree with management policies; technology is not well suited for the worker/task/organization; or organization is harming the environment; environmental factors influence work.

This model is adopted for reaching both objective #1 and objective #2. For the former goal, MA will be primarily used to identify the mechanism of electrical hazards and the relationship among variable. For the latter goal, MM will assist to design the training program and prototype.

Retrospective Content Analysis

A retrospective content analysis (RCA) study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a "real life" context (Simons, 2009). RCA can be defined as a case study in which criteria are established for selecting cases from historical records for inclusion. It inherits the essence of learning from past and aims at sharpened understanding of why the instance happened.

This analysis technique is adopted as a fundamental method throughout entire research for reaching objective #1, objective #2 and objective #3.

Chi-squared Automatic Interaction Detector (CHAID)

Chi-squared Automatic Interaction Detector (CHAID) is a type of decision tree technique, based upon adjusted significance testing. In practice, CHAID is often used in the context of direct marketing to select groups of consumers and predict how their responses to some variables affect other variables, although other early applications were in the field of medical and psychiatric research (Chi et al., 2012).

Like other decision trees, CHAID's advantages are that its output is highly visual and easy to interpret. Because it uses multi-way splits by default, it needs rather large sample sizes to work effectively, since with small sample sizes the respondent groups can quickly become too small for reliable analysis.

This CHAID technique is specially adopted for reaching objective #2.

Decision-tree Mapping

The box-and-arrow diagram is a technique for modeling process flow, showing the steps as boxes of various kinds, and their order by connecting them with arrows (Ross, 1985). Specifically, the IDEF0, as a kind of the box-and-arrow diagram, is applied in this research for model the decisions, actions, and activities of an organization or system.

IDEF0 is used to show data flow, system control, and the functional flow of lifecycle processes. IDEF0 is capable of graphically representing a wide variety of business, manufacturing and other types of enterprise operations to any level of detail. It provides rigorous and precise description, and promotes consistency of usage and interpretation. It is well-tested and proven through many years of use by government and private industry. It can be generated by a variety of computer graphics tools.

This mapping method will be specially adopted for reaching objective #2.

Association Analysis

Association analysis (AA) is a useful mathematical technique for discovering interesting relationships hidden in large datasets. Typical AA techniques include Chi-squared test and T-test.

This AA technique will be especially adopted for reaching objective #1 and objective #3.

1.5.4 Reliability and Validity

Reliability is the extent to which an experiment, test, or any measuring procedure yields the same result on repeated trials. Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure (Guion, 2002). In other words, as Figure 1-8 illustrates, validity means whether a research measures is of accuracy while reliability means whether a measure of consistency.

Figure 1-8. Reliability and validity.

In order for measures to be sound, they must be free of bias and distortion. Reliability and validity are two concepts that are important for defining and measuring bias and distortion (Golafshani, 2003; Guion, 2002). To maximize the validity and reliability of expected outcome, this research adopts following two major countermeasures:

PDCA (Plan-Do-Check-Act) Process

The PDCA process works especially when establishing a factor framework. Finalizing factors with representativeness cannot be done in a step, rather, it requires continuous testing and reversions. PDCA process is just the appropriate strategy that addresses this require cycle.

Expert Panel Consultancy

Consistent communication with a safety expert panel ensure the researcher to assess accident attribute and evaluate factors accurately. Particularly, this panel consisted of not only faculties but also FACE investigators from NIOSH. For example, the research consulted with Massachusetts and Kentucky FACE program professionals who wrote the FACE reports. These experts have on average more than ten years of experience in the area of construction safety. This consultancy largely helped to ensure researcher correctly understanding the fatal reports and coding factors precisely in narrative text analysis.

1.6 CONTRIBUTION

Along with the goals of this study, the work aims to contribute broadly to the construction industry in the following two forms:

The first form of contribution comes to the body of safety knowledge. Findings from this dissertation contribute to (a) better demonstrating the mechanism of electrocution and the relationships among contributing factors in construction; (b) increasing the prevention efficiency for real-life practices; and (c) building a basis for more innovative control measures in features of work.

The other form of contribution comes to the methodological knowledge for safety research. This work introduces multiple innovative approaches in exploring construction safety and control measures. These approaches use a systems engineering perspective and are applicable to broad safety research in the construction area and beyond.

1.7 DOCUMENT STRUCTURE

The dissertation will be completed using the manuscript process that is approved by the Virginia Tech Graduate School and the Department of Building Construction with support of necessary chapters to provide more complete and detailed information.

The dissertation consists of the following six chapters and two appendices as follows:

- Chapter 1: Introduction – the background, research problems, objectives, and overall design of the dissertation.
- Chapter 2: Literature Review – a review of relevant literature related to the research.
- Chapter 3: Sociotechnical Systems of Fatal Electrical Injuries in the Construction Industry - a systems analysis on construction electrocution to explore the internal interactions with the work system.
- Chapter 4: Decision-making Chains in Electrical Safety for Construction Workers – an examination on electrocution mechanisms in terms of decision making.
- Chapter 5: Control Measures of Electrical Hazards – an assessment on the effectiveness of control measures and prevention strategies using a hierarchy of controls.
- Chapter 6: Conclusions – a summary of the entire research and findings.
- Appendix A: Electrical Deaths in the U.S. Construction – one of the author's prior publication serving as a point of departure for this dissertation.
- Appendix B: FACE Case Summaries – a collection of summaries of all the fatality cases used as research data in this dissertation. The author directly obtained the summaries from FACE dataset without editing.

CHAPTER 2.
LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is conducted in support of research topics on sociotechnical system, human factors, occupational safety and health, construction work environment, and quantitative-and-quantitative-mixed methods.

It is important to understand philosophies of human error from existing human factor models and theories towards examining accident causation of electrocutions among construction workers. Literature views the role of human error in a sociotechnical work environment (workers, technologies, work processes, environments) in which electrical fatality occurs. This theoretical background is fundamental to the following research processes, such as data collection and analysis method determination, within the "*Research Path*" (see Figure 1-4).

Understanding characteristics of a data source is also important for researcher to appropriately utilize it towards achieving research goals. Especially for this research, fully understanding the benefits and limits of using external data, namely performing meta-analysis of a third party's data verses collecting data *per se* can ensure reliability and validity of the outcome's quality. Thus the review of literature in this work also focuses on the appropriate strategies for data selection and collection.

The author reviews literature on methodologies to justify the appropriateness of applied analysis methods. For example, should factors be assessed using quantitative metrics or qualitative indicators? The preliminary proposal suggested the use of CHAID as a method to classify electrocution patterns. Why is CHAID the best choice, compared to other classification methods? The methodology part of the literature review identified several classification algorithms, compares and contrasts the various approaches, and explains why CHAID (or a different) classification approach is ideal in this specific application.

2.2 TERMS AND DEFINITIONS

Definitions of relevant terms are as follows:

Sociotechnical System (STS): an approach to complex organizational work design that recognizes the interaction between human and technology in a work environment (Pasmore & Sherwood, 1978).

Macroergonomics: a process which is based on STS theory and utilizes the STS mechanism to analyze the sociotechnical subsystems of a work system, and determine their effects on the three organizational design dimensions of complexity, formalization, and centralization (Hendrick & Kleiner, 2002).

Human Factors: a scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (International Ergonomics Association, 2014). It includes physical ergonomics, cognitive ergonomics, and organizational ergonomics (i.e., macroergonomics).

Human Errors: a deviation from human intention, expectation or desirability that results in one or more unintended negative outcomes and negatively influence human reliably and organizational productivity in a sociotechnical system (Reason, 1990; Senders, Moray, & Organization, 1991).

Hierarchy of Control (HOC): the Hierarchy of Hazard Control, is a system used in industry to minimize or eliminate exposure to hazards. The Centers for Disease Control and Prevention (2014) defines the controls in the hierarchy as, in order of decreasing effectiveness from top to bottom:

- Elimination
- Substitution
- Engineering
- Administration

- Personal protective equipment

2.3 Point of Departure

Prior research suggested that learning from failure is an effective means to counteract system failures, some of which may cause fatal injuries. As a result, learning from respective fatalities presents one possible solution for diagnosing and correcting current safety errors. This research follows the path of the previous work done by the author in his Master's research, based on which the published outcome (Zhao, Thabet, McCoy, and Kleiner, 2014) is the point of departure for this dissertation (see Appendix A).

Findings from Zhao, Thabet, et al. (2014) revealed typical features of electrical accident fatalities in construction and provide common electrical safety challenges on construction sites. For example, extra care with electrical hazards should be taken when working in hot weather since electrical fatalities are significantly dense in summer, especially in August. Both exposed working environments in construction and relatively high frequency of construction projects during this season pose another explanation. Firms such as construction equipment contractors, utility construction contractors and residential builders are commonly involved in electrical accidents and should pay particular attention to electrocution prevention efforts for their employees, at a minimum the OSHA required. Especially, the number of violation of OSHA regulation is disproportionately high for residential builders. Occupations particularly susceptible to electrocution include line installer and repairer, construction laborer, electrician and construction machine operator. Data also suggest that young male workers within the age 25 to 44 bear higher risk of getting electrically shocked. Such age data might also include young construction workers (within the lower part of this age range) that are less matured in hazards awareness and lack safe practical experiences, which could be a topic of future research. Outdoor tasks involving power lines, boomed vehicles and supporting equipment such as ladders and scaffolds are exposed to a relatively higher electrical risk and thus require additional safety training and possible countermeasures. More than half of construction electrocutions originated from power lines for local distribution systems with voltage ranging from 1 kV

(1kV=1,000 volts) to 16 kV, which are worthy of special attention in terms of hazard surveys and safety inspections.

While previous work established a basic understanding of electrocution in U.S. construction, it only described surface-based features of fatality in a personnel approach however did not address the causation mechanisms in a systems approach. This work continues this line of inquiry to explore electrical fatal accidents using FACE data sources but extends the research areas into causation mechanisms and control measures using a systems perspective.

2.4 SOCIOTECHNICAL SYSTEMS

The sociotechnical system (STS) model was empirically developed in the late 1940s and 1950s by Emery and Trist, and refined by Katz and Kahn (1966). This model views organizations as systems of transformative agencies which transform inputs into outputs. Sociotechnical systems theory highlights three elements within this transformative process: technological subsystem, personnel subsystem, and work system design consisting of an organizational structure and processes. These three elements interact with one another and the external environment on which the organization depends for its survival and success. Compared with micro-level human factors (e.g., human-machine interface) engineering, new is a sociotechnical system theory that focuses on organizational design, job design and change management in a higher bird view on a macro-level.

Hendrick and Kleiner (2002) promoted such macro-level sociotechnical model and named it Macroergonomic Analysis and Structure (MAS) for analyzing work system. This model involves two or more people interacting with some form of:

(a) hardware and/or software;
(b) internal environment;
(c) external environment; and/or
(d) an organizational design.

The model combines empirically-developed analytical models of the effects of three major sociotechnical system elements, the technological subsystem, personnel subsystem and relevant external environment, on the fourth major element, the structure of the organization's work system (see Figure 2-1).

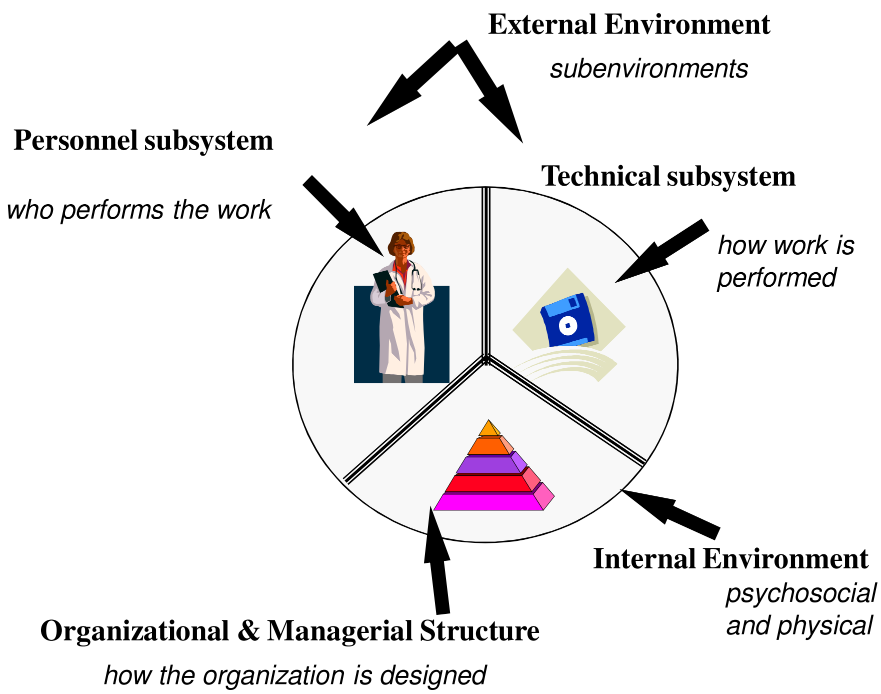


Figure 2-1.Work system in the macroergonomic analysis of structure (MAS).

Built on the MAS work system, Kleiner (2006) refined an analysis process, which is MacroErgonomic Analysis and Design (MEAD). This method triangulated other methodologies of microergonomics, total quality management (TQM) and sociotechnical systems (STS) in a common approach (Kleiner, 1999). MEAD highlights ten specific steps in evaluating work system, as shown in Figure 2-2.

1. Scanning the environmental and organizational design sub-system
2. Defining production system type and setting performance expectations
3. Defining unit operations and work process
4. Identifying variances
5. Creating the variance matrix
6. Creating the key variance control table and role network
7. Performing function allocation and joint design
8. Understanding roles and responsibilities perceptions
9. Designing/redesigning support sub-systems and interfaces
10. Implementing, iterating and improving

Figure 2-2. Ten steps in MEAD (used with permission from Kleiner, 2006).

The macroergonomic theory (e.g., MAS or MEAD) was demonstrated to be capable to fill the void in human factors and ergonomics, especially in the optimization of organizational and work systems design through consideration of relevant personnel, technological and environmental variables and their interactions (Hendrick & Kleiner, 2002; Kleiner, 2006; Smith-Jackson & Klein, 2009). Further, macroergonomic theory can be applied for Occupational Safety and Health (OSH) in the AEC industry (Haro & Kleiner, 2008). For example, Kleiner et al. (2008) designed a Rapid Universal Safety and Health System (RUSH) and deployed it in a 106-hour construction project, using macroergonomic theory. The result of five days no recordable incidents provided a positive validation for this application. Also, this study established a sociotechnical system in construction safety of which components were identified as:

- Technical subsystem - manner in which work is performed: heavy machinery, equipment, power tools, hand tools, methods and procedures;
- Personnel subsystem: sociocultural and socioeconomic characteristics of the construction workers, including selection and training;
- External environment: political, economic, technological, educational, and cultural forces;
- Internal environment: physical and cultural job site;

- Organizational and management structure: formal or informal.

All aforementioned research provides a good base for this research on construction electrocutions. The macroergonomic model can be used to optimize the OSH work system and can also be used to diagnose problems in failed OSH work system, e.g., construction accidents.

2.5 HUMAN ERRORS

Reason (1990) combined the knowledge-based and rule-based errors into human mistakes and extended human error as three types: skill-based errors, mistakes and violations. Skill-based errors derive from the limited capacity of information processing resources, including attention. Mistakes occur when personnel have sufficient skill but unintentionally violate protocol. Violations occur when personnel have appropriate skill but intentionally violate protocol. Violations are distinct from errors in that they are intentional (Reason, 1990, 2000).

Regarding construction electrocution, current studies often apply this human error view (Cawley & Homce, 2008). As a result, surface causes, such as contacting overhead power lines, have been determined using statistical calculation of human error while possible mechanisms are rarely addressed.

In response to human error control, insufficient training is a significant reason for fatality occurrence and providing an effective and enhanced training program is the core for prevention and control. Human errors can result from the lack of knowledge or task inexperience (Hasan & Jha, 2012). Jaselskis, Anderson, and Russell (1996) determined that less frequency in safety training, as one of these key factors, influences work execution that may lead to unsafe practices and incidents. Administrative controls such as training and personal protective equipment (PPE) are mandatory measures, whose reduction of risk is a final layer of protection and not a protection strategy necessarily. It is not the causation of accidents but systematic biases that undermine safety management strategies (Woodcock et al., 2005).

2.6 ACCIDENT CAUSATION MODEL

A study from Lehto and Salvendy (1991) reviewed 54 different accident causation models and 16 methods of application and classified four groups of causation model, which are:

(a) general models of accident process;
(b) models of human error and unsafe behavior;
(c) models of the mechanics of human injury; and
(d) model on application techniques.

Another study from Khanzode, Maiti, and Ray (2012) generalized four accident causation theories, which are:

(e) accident proneness theory;
(f) domino theory;
(g) injury epidemiology theory; and
(h) system theory.

While the author partially agrees with the above arguments, a re-classification of existing causation models into two general groups based on the standpoint on human error could be useful. These two groups are the personnel perspective group and systems perspective group. Researchers cannot judge either of them is more advanced than the other, as standpoints work like two lenses through which one can view accident causation with different emphases. Also, both standpoints have advocates and applications. In the following paragraphs, the author will discuss the role and adoption of human error in these two standpoints.

Person- Perspective

The Person- Perspective always explores causes of accident occurrence through a prism of human fallibility. This standpoint is especially adopted in human factors causation models, in which human error is widely considered as the key factor contributing to up to 80% of occupational accidents in the aviation, petrochemical, healthcare, construction, mining, and nuclear power industries (Hetherington, Flin, & Mearns, 2006). Haslam et al. (2005)

supported this point with findings in which worker actions and behaviors, as an involving factor, determined 49% of construction accidents. Rasmussen (1997) also found that human error was a determining factor in 70 - 80% of accident cases. Many literatures agreed with and applied this perspective in their causation models. Garrett and Teizer (2009) used examined human errors in construction in its human factors analysis classification system (HFACS) model; Shin, Lee, Park, Kwon, and Kim (2013) preset worker's human errors as the main triggering factor of accidents and dealt with the paths related with the human errors as the main accident causation in the Accident Earth Model. The Europe's Major Accident Reporting System (MARS) also applies human factors model and collect accident information in terms of human factors data (Baranzini & Christou, 2010).

The personnel perspective applied in the architecture, engineering and construction (AEC) industry focuses on the human behavior and the reason leading to human errors. Toole (2002) concluded eight factors to prevent root causes of construction accident. These factors are, for example, lack of proper training, poor attitude toward safety, or not using provided safety equipment. Obviously, the key assumption in this type of model is that the behavior of individual employees is sometimes the primary cause of an accident. This type of human behavior-focused causation models are also seen from studies of (Abdelhamid and Everett (2000); Feng (2013); Gibb et al. (2001); Suraji, Duff, and Peckitt (2001)); and Gordon, Flin, and Mearns (2005). In other words, the personnel perspective stresses on human factors as the mismatch between human's behavioral requirement and their responding capacity, which will reflect in the behavioral outcomes (Bellamy, Geyer, & Wilkinson, 2008).

Although the personnel perspective takes into account organizational factors and environmental factors, it only considers them as external elements which would indirectly influence accident occurrence through direct influence on human performance. Human factor is not the only factor but is the essential factor that results in cumulative impact on performance (Edwards, Sharples, Wilson, & Kirwan, 2012). As shown in Figure 2-3, the human error under personnel issues, as "an action or decision that results in one or more unintended negative outcomes" defined by Strauch (2002) is the immediate accident causation. In comparison, the organizational, managerial or design issues are contributing factors which associate with a particular type of human error in accident causation (Busse, 1999; Hobbs & Williamson, 2003; Rooney, Vanden Heuvel, Lorenzo, Stoecklein, & Christensen, 2002). Typical human errors in accidents are related to aberrant mental processes such as forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness (Reason, 1988).

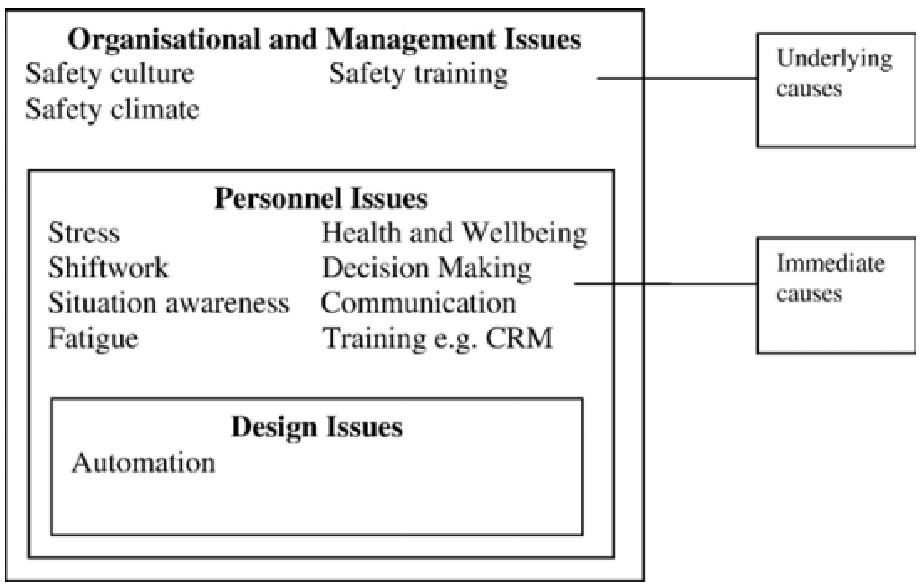


Figure 2-3. Causation structure from the personnel perspective.

Source: Hetherington et al., (2006).

Systems perspective

The systems perspective considers human errors as consequence rather than cause, having the causation not so much in the perversity of human nature but in "upstream" systemic factors (Reason, 2000). Compared to personnel perspective, the assumption that human factor is critical causation does not exist and, rather, human issues are considered as same as organizational or environmental factors. The contributory factor could but not necessarily be human error (Hanninen & Kujala, 2012). Rather, organizational breakdowns seem to provide an essential contribution to accident occurrence (Kleiner et al., 2008; Zhao, Thabet, et al., 2014). This viewpoint of causation is also commonly associated with a failure in completing a task (Strauch, 2002).

The application of a systems perspective includes two different emphases: one is on process and the other on relationship. The process-centered causation approach concentrates on the physical consequence, namely “how” an accident occurs in the information process chain. Some examples of process-centered system model are the Accident Root Causes Tracing Model (Hinze, Pedersen, & Fredley, 1998); Event Process Model (Rizzi & Pedersen, 1992); Cause-consequence Model (Jørgensen, 2011); and the Systems Theoretic Accident Modeling and Processes (STAMP) model (Leveson, 2004). Specifically, STAMP model focuses on information distribution path and the interactions between system components and the control mechanisms. It views system as hierarchical levels of controls and constraints, with each level in the hierarchy imposing constraints on the level below. Meanwhile, the relationship-centered causation approach focuses on sociotechnical associations within the whole accident system, namely “why” an accident occurs. For example, the AcciMap Model (Rasmussen, 1997) focuses on failures across the six organizational levels: government policy and budgeting; regulatory bodies and associations; local area government planning and budgeting technical and operational management; physical processes and actor activities; and equipment and surroundings. Another example is the Macroergonomic Model (Kleiner, 2006) that focuses the interactions in a sociotechnical system in terms of hardware and/or software, internal environment, external environment, and/or an organizational design.

In the AEC industry, the adoption of a systems perspective might improve the limits of accident causality in personnel perspective which underestimates the work system factors and their interactions that generate the hazardous situations and shape work behaviors (Arboleda & Abraham, 2004). For example, Mitropoulos, Abdelhamid, and Howell (2005) analyzed three types of error (the task, the environment, and the workers’ capacity) to determine accident causation in construction projects, and argued that not all errors release hazards as many errors are inconsequential or trapped by system. In other words, human error is no longer the only causation responsible for incident occurrence.

In summary, existing accident causation models view the role of human error in two different perspectives: personnel and system. Both perspectives can be applied in the analysis of electrocution accidents in workplace. The difference of the two is the status of human error: one as critical causation whiles the other as ordinary casual possibility. Specifically in construction, the needs of systematic analysis must extend beyond the operations of an individual or single organization and include an analysis of the roles, relationships, and actions of parties not traditionally engaged in the management of site-based work (e.g., owners/clients, architects and engineers and designers and suppliers of equipment, vehicles, and tools and materials). Particular attention needs to be directed to the interfaces between the multiple professional, technical, and managerial stakeholders of the construction supply chain, as it is these interfaces where variances exist and critical improvements can be made.

2.7 HIERARCHY OF CONTROLS

A growing recognition that the evaluations of OSH practices should assess the quality and effectiveness of risk control outcomes (Linden, Trochim, & Adams, 2006; Lombardi, Verma, Brennan, & Perry, 2009). The idea behind this hierarchy is that the control methods at the top of the list are potentially more effective and protective than those at the bottom. As Figure 2-4 shows, following the hierarchy normally leads to the implementation of inherently safer systems, ones where the risk of illness or injury has been substantially reduced.

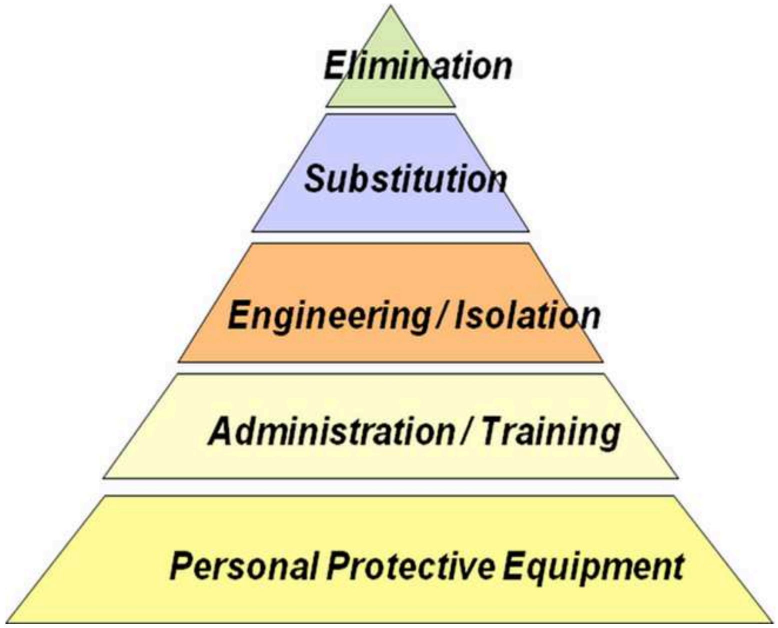


Figure 2-4. Pyramid of the hierarchy of controls.

According to the Centers for Disease Control and Prevention (2014), this hierarchy is explained as follows:

Elimination and substitution, while most effective at reducing hazards, also tends to be the most difficult to implement in an existing process. If the process is still at the design or development stage, elimination and substitution of hazards may be inexpensive and simple to implement. For an existing process, major changes in equipment and procedures may be required to eliminate or substitute for a hazard.

Administrative controls and personal protective equipment are frequently used with existing processes where hazards are not particularly well controlled. Administrative controls and personal protective equipment programs may be relatively inexpensive to establish but, over the long term, can be very costly to sustain. These methods for protecting workers have also proven to be less effective than other measures, requiring significant effort by the affected workers.

Engineering controls are used to remove a hazard or place a barrier between the worker and the hazard. Well-designed engineering controls can be highly effective in protecting workers and will typically be independent of worker interactions to provide this high level of protection. The initial cost of engineering controls can be higher than the cost of administrative controls or personal protective equipment, but over the longer term, operating costs are frequently lower, and in some instances, can provide a cost savings in other areas of the process.

2.8 SECONDARY DATA ANALYSIS

As Figure 2-5 shows, research data sources include primary data and secondary data. The difference between primary and secondary data is only “a change of hand” (Boslaugh, 2007; Kumar, 2005). The primary data is the first hand information which is directly collected form by a researcher through observations, experiments, surveys, questionnaires, focus groups, and interviews. They are the most original data in character and have not undergone any sort of statistical treatment. In contrast, the secondary data are obtained from some other sources or agencies which could be statistical census, government or committee reports, association records, technical journals, and public newspapers. They are not original in character and have undergone some treatment at least once. The same data set can be a primary data set to one researcher and a secondary data set to a different researcher (Thapa & Burtch, 1991).

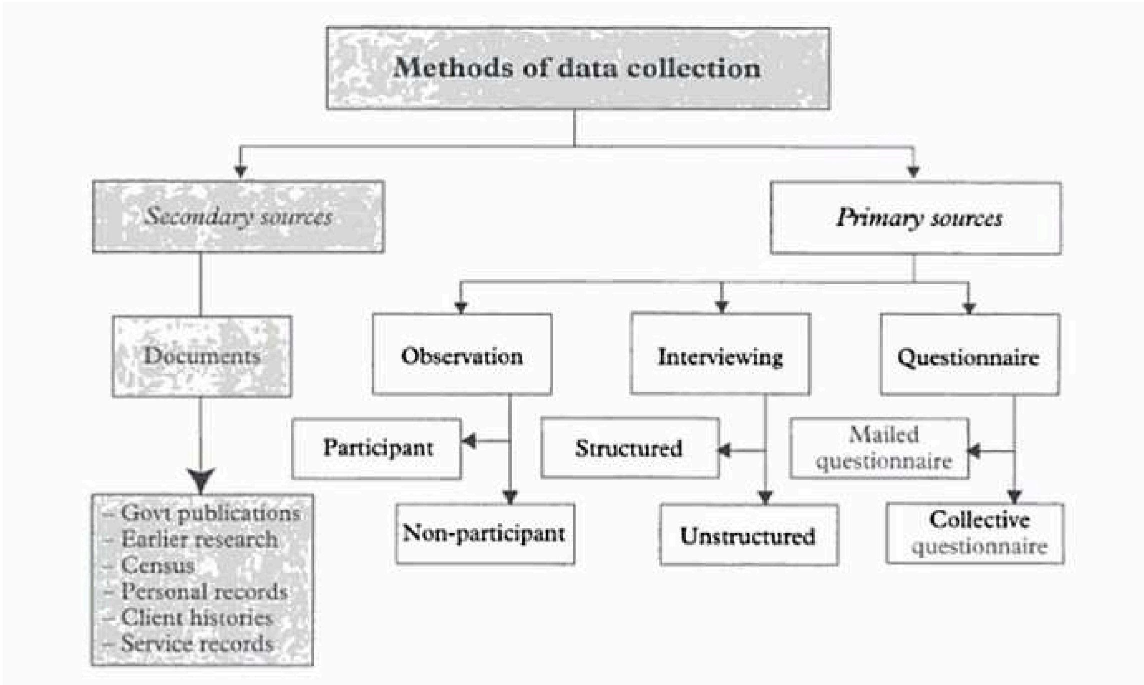


Figure 2-5. Data collection sources.

Source: Kumar, (2005).

Boslaugh (2007) highlighted three major advantages of using secondary data which are data availability, data breadth and data economics. Data availability means that the data collection process is often guided by expertise and professionalism that may not be available to individual researchers or small research projects. Data breadth means the numerous studies on a large, national scale that individual researchers would have a difficult time collecting, and this breadth may allow researchers to look at trends and changes of phenomena over time. Data economics indicate that researcher does not have to devote money, time, energy, and other resources to this phase of research.

All above advantages of secondary data apply to the FACE reports in this research. Especially, this data source could overcome the biggest disadvantage of primary data that accident occurrence cannot be designed or observed at any moment. On the contrary, data collection requires continuously long-time surveillance, for example, tens of years of time for data collecting. This reason is critical for the decision on choosing secondary data as research data source in this research.

Many surveillance data sources, particularly those relying on aggregate coded data, lack the detail and granularity needed to understand the complexity of the injury event and design effective injury prevention initiatives (McKenzie, Scott, Campbell, & McClure, 2010). As Higgins, Casini, Bost, Johnson, and Rautiainen (2001) pointed out, surveillance data sources such as the Traumatic Occupational Injury Resources (NTOF) and the Census of Fatal Occupational Injuries (CFOI) are useful for identifying common causes of large numbers and/or rates of occupational injury death; however FACE provides more in-depth information to understand the circumstances and contributors to fatal injuries for developing effective prevention measures. FACE reports are superior with explicit case investigation, detailed process narrative and professional recommendation over other NORA recommended sources of only statistical numbers (Zhao, Thabet, et al., 2014). Further, FACE-based research findings have been published in scientific and safety journal (Bunn & Struttmann, 2003; Hammond, Rischitelli, & Zoller, 2012; Higgins et al., 2001; Kunadharaju et al., 2011), or validated by safety professionals and policy makers (Bunn, Slavova, & Hall, 2008; M. A. Cohen, Clark, Silverstein, Sjostrom, & Spielholz, 2006). Therefore, all of above have endorsed FACE reports' value as a reliable data source in the Occupational Safety and Health (OSH) research including this research on construction electrocution.

2.9 Narrative Information Analysis

Narrative information in fatality investigation reports contains data elements not routinely analyzed with coded occupational injury surveillance data (Bunn et al., 2008; Langley, 1995). The goal of narrative text analysis is to extract and explore useful hidden information through analytical methods (e.g., natural language processing) turning text into data. Specific text analysis methods include information retrieval, lexical analysis to study frequency distributions, pattern recognition, tagging/annotation, information extraction, text mining, visualization and predictive analytics. Typical text analysis tasks include text categorization, text clustering, concept/entity extraction, granular taxonomies production, sentiment analysis, document summarization, and entity relation modeling (Cohen & Hunter, 2008).

Particularly in OSH research, methods such as manual review and coding approaches, text search methods, and statistical tools have been utilized to extract data from narrative text and translate it into useable, detailed injury event information (McKenzie et al., 2010). In other words, the major approaches to narrative text analysis for injury surveillance which have been used include: a) manual review and recoding methods using relevant standardized classification systems to capture additional information from text fields (Hammig, Yang, & Bensema, 2007; Sikron, Glasser, & Peleg, 2007); b) keyword searches using either individual words or detailed indexes of words to select cases and identify additional information of interest (Dement, Lipscomb, Li, Epling, & Desai, 2003; Farmakakis et al., 2007); and c) semi-automated computer-based approaches using Bayesian/clustering principles to categories cases based on broad injury elements of interest (Brooks, 2008; Smith et al., 2006; Wellman, Lehto, Sorock, & Smith, 2004).

Narrative text data and relevant methods have been widely utilized in OHS research. McKenzie et al. (2010) reviewed 41 technical publications which used narrative text analysis in OSH research, and concluded that narrative text analysis can and have been applied to add value to previously coded injury datasets. They also generalized the main strengths of narrative text-based methods to injury surveillance as follows: a) narrative text methods enable the identification of cases which are unable to be identified through alternative classification schema; b) allow for capturing sequential chain-of-event information which is not able to be fully captured in single codes; and c) can be used to identify systematic errors in coding and limitations of the classification systems. Further, these advantages resulted in this methodology’s wide adoption in OSH research fields (Kemmlert & Lundholm, 2001; Smith et al., 2006) such as agriculture (Bunn et al., 2008), forestry (Bentley, Parker, & Ashby, 2005), manufacture (Bulzacchelli, Vernick, Sorock, Webster, & Lees, 2008; J. W. Collins, Smith, Baker, Landsittel, & Warner, 1999; J. W. Collins, Smith, Baker, & Warner, 1999; Warner, Baker, Li, & Smith, 1998), transportation (Bunn & Struttmann, 2003), utility (Fordyce, Kelsh, Lu, Sahl, & Yager, 2007), construction (Dement et al., 2003; Lombardi et al., 2005), and even military (Lincoln et al., 2004).

Narrative text analysis is also appropriate for safety research in the Architecture, Engineering and Construction (AEC) industry (Bondy, Lipscomb, Guarini, & Glazner, 2005). Glazner, Bondy, Lezotte, Lipscomb, and Guarini (2005)used these methods in analyzing 4,000 injury reports for the construction of Denver International Airport, and concluded that narrative descriptions from injury reports can provide detail on circumstances surrounding injuries and identify factors contributing to injury. Bondy et al. (2005) suggested these methods could guide investigators to explicitly consider human, organizational, and environmental factor, and thus foster more complete descriptions of factors contributing to construction injury. Using same methods, Dement et al. (2003) investigated the occurrence of nail gun-associated injuries among construction workers and identified preventable work-related factors associated with these injuries. Through coding text descriptions, Lipscomb, Glazner, Bondy, Lezotte, and Guarini (2004) identified circumstances surrounding falls and suggested that text analyses allow exploration of factors not identified at the time of data collection and better understanding of the context in which injuries occur. Lombardi et al. (2005) utilized a hybrid narrative coding method to determine activities and circumstances proximal to a welding related occupational eye injury, and concluded that narrative injury text provides valuable data to supplement traditional epidemiologic analyses.

FACE reports are believed to be eligible narrative injury sources and have been adopted in many safety-related research. Bunn et al. (2008) conducted a narrative text analysis of 69 FACE agricultural tractor fatality reports and found that narrative text analysis using keywords and text strings has a high degree of sensitivity, and provides supplemental information on additional unknown risk factors. Cohen et al. (2006) analyzed FACE fatality reports of Washington State to discover incident characteristics and develop potential prevention measures. Hammond et al. (2012) compared data from FACE and CFOI from 2003 to 2007, and found that FACE reports data could capture 78% of CFOI surveillance systems, and both of which provide same inclusion criteria. Kunadharaju et al. (2011) examined 189 FACE reports on firefighters and summarized the most effective control measures for safety promotion. In sum, FACE reports have contributed to the formulation and dissemination of diverse strategies for preventing fatal occupational injuries (Higgins et al., 2001).

The above three points with emphases on OSH, AEC and FACE data support the argument that a combined methodology of text analysis and sociotechnical system theory is appropriate, valid and acceptable in this research on construction electrical fatalities.

2.10 Decision-tree Classification

The family of decision-tree classifications (see Figure 2-6) includes many techniques. The most popular and most often-used criterion-based classification techniques are automatic interaction detection (AID); chi-squared automatic interaction detection (CHAID); classification and regression trees (CART); quick, unbiased, efficient statistical tree (QUEST); and C5.0/C4.5 (Tufféry, 2011; van Diepen & Franses, 2006). The author will discuss these techniques one by another in next paragraphs.

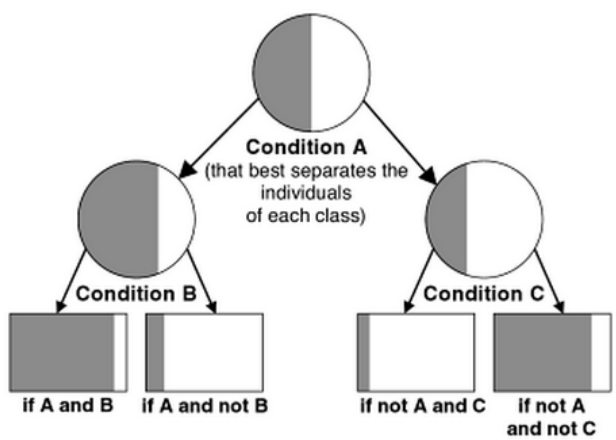


Figure 2-6. Decision tree classification diagram.

Source: Tufféry (2011)

2.10.1 Typical Decision-tree Techniques

Automatic Interaction Detection (AID)

Automatic Interaction Detection (AID), as a statistical technique for multivariate analysis, involves a successive series of analytical steps that gradually focus on critical determinants (Hawkins & Kass, 1982). Sonquist and Morgan (1964) first developed the AID algorithm that seeks sequential partitioning of the observation matrix to identify and segregate subgroups individually (Ali, Hickman, & Clementson, 1975). In essence, AID is a branch-and-bound application of a one-way analysis of variance model under predetermined bounds and constraints (Kass, 1975). The aim of this technique is to split the data successively by binary divisions into a number of subgroups. Of the possible splits, AID chooses what minimizes the "residual sum of squares" of the dependent, which is equivalent to maximizing the between subgroup sum of squares (BSS) in the analysis of variance (ANOVA) terminology(Kass, 1975). For example, AID result partitions the reordered data set into two mutually exclusive subgroups of which the BSS is the highest (in Figure 2-7, the BSS of Group 2 and 3 is 5.4694), then continuously repeats this way until reaching the final group classification tree (see Figure 2-8).

Split Group 1 into Groups 2 and 3 by predictor 7 in step 1

Predictor levels or classes	Class population	Mean $\bar{y}$ (descending order)		BSS ($\times 10^6$)
1	58	516·33	Group 2	
0	53	496·00		1·4518
3	38	483·29		2·8662
2	40	467·20		4·0523
				5·4694
5	59	273·66	Group 3	
7	45	264·33		3·3114
4	64	251·19		2·1261
6	43	246·72		1·3263

Figure 2-7. AID partitioning mechanism (used with permission from Ali et al., 1975)

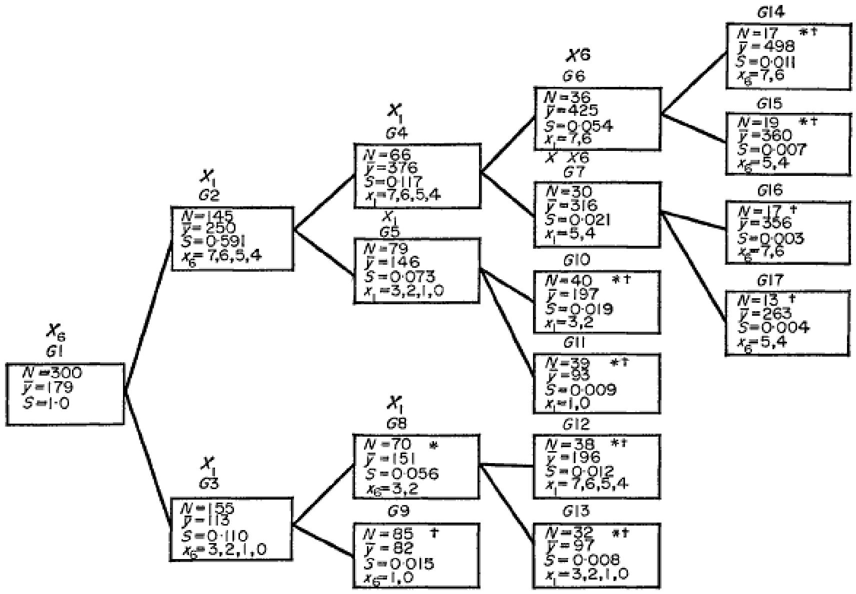


Figure 2-8. Example of AID partitioning tree

Source: Ali et al., (1975)

AID has been used as a multivariate tool in social sciences, economic and econometric model building (Ali et al., 1975; Hasan & Jha, 2012; Jaccard, Wan, & Turrisi, 1990). With AID, the researcher can explore the relationship, the inter-correlation and the interaction between variables while reducing the problem size. AID prefers continuous variables in multiple Regression (Jaccard et al., 1990)

CHAID evolved from AID (van Diepen & Franses, 2006), which will be discussed in the next section.

Classification and Regression Trees (CART)

CART technique is a classification method developed in the 1980s by Breiman, Friedman, Stone, and Olshen (1984) to construct decision trees (either classification or regression trees). CART usually uses a learning sample (a set of historical data) with pre-assigned classes to classify new observations. The CART algorithm seeks for all possible variables and all possible values in order to find the best split – asking only yes-or-no questions to split the data into two parts with maximum homogeneity (Maronna, 2011). This process is then repeated for each of the resulting data fragments. Witten and Frank (2005) defined the

CART process as the splitting repeating of each two subgroups until the homogeneity criterion is reached or until some other stop criterion is met.

The Classification tree is built on splitting rules (e.g., the Gini index or the Twoing splitting rule). These rules perform the splitting of learning sample into smaller parts (see Figure 2-9).

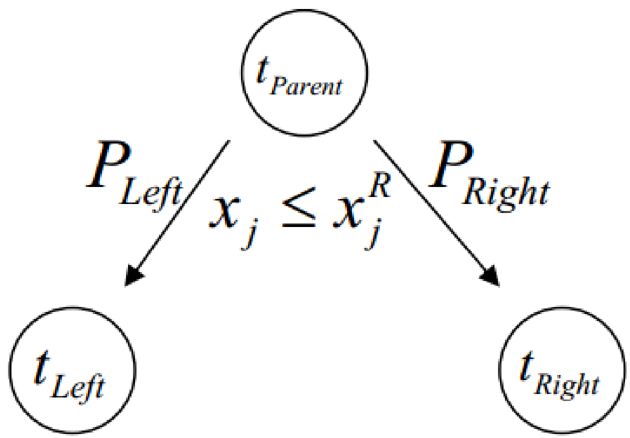


Figure 2-9. CART splitting algorithm.

Source: Breiman et al., (1984)

In contrast, regression trees do not have pre-assigned classes, the splitting is conducted based on squared residuals minimization algorithm which implies that expected sum variances for two resulting nodes should be minimized.

$$\underset{x_j \leq x_j^R,\ j=1,\ldots,M}{\arg\min} \quad [P_l \mathrm{Var}(Y_l) + P_r \mathrm{Var}(Y_r)]$$

(Equation 2-1)

where $Var(Y_l)$, $Var(Y_r)$ are response vectors for corresponding left and right child nodes.

Quick, Unbiased, Efficient Statistical tree (QUEST)

QUEST is a binary-split decision tree algorithm for classification and data mining developed by Loh and Shih (1997). Similar to CART, QUEST is an alternative binary-split decision tree algorithm for data classification. The QUEST algorithm resembles the CART algorithm, except that the QUEST algorithm uses an unbiased variable-selection technique as its default and applies imputation instead of surrogate splitting to deal with missing values. Therefore, QUEST can easily handle categorical predictors with many categories.

Lim, Loh, and Shih (2000) compared QUEST and other similar algorithms and concluded that QUEST is the most accurate decision tree algorithm with linear splits. They also commented that the QUEST and logistic regression algorithms are substantially faster.

C5.0/C4.5

Quinlan (1993) developed a classification technique C4.5 and then improved it into C5.0, a set of computer programs that construct classification models (Kotsiantis, 2007). This algorithm obtains decision trees featuring boosting technology to enhance accuracy in identifying samples. At each node of the tree, C5.0 chooses the attribute of the data that most effectively splits its set of samples into subsets enriched in one class or the other. The splitting criterion is the normalized information gain (difference in entropy). With the maximum information gain, each subsample defined by the prior split is then split again until the subsamples cannot be split any further. Finally, the lowest-level splits are reexamined, and those that do not contribute significantly to the value of the model are removed or pruned (Tan, 2006). Specifically, with C5.0, the number of splits performed equals the number of categories, generating a ‘‘bush-like’’ structure. Notably, C5.0 uses training data when growing and pruning trees (Shmueli, Patel, & Bruce, 2011).

C5.0 models are quite robust in the presence of problems such as missing data and large numbers of input fields. They usually do not require long training times to estimate. In addition, C5.0 models tend to be easier to understand than some other model types, since the rules derived from the model have a very straightforward interpretation. C5.0 also offers the powerful boosting method to increase accuracy of classification.

2.10.2 Comparison

CHAID is an classification algorithm introduced by Kass (1980) as an improvement of an earlier version of AID (Kass, 1975) to study the relationship between a dependent variable and a series of predictor variables, especially for large quantitates of categorical data. Biggs, De Ville, and Suen (1991) then improved CHAID into Exhaustive CHAID, both of which allow multiple splits of a node and include three steps: merging, splitting and stopping. A tree is grown by repeatedly using these three steps on each node starting from the root node (see Figure 2-10). The difference of CHAID and Exhaustive CHAID is that during the merging step the Exhaustive CHAID uses an exhaustive search procedure to merge any similar pair until a single pair remains.

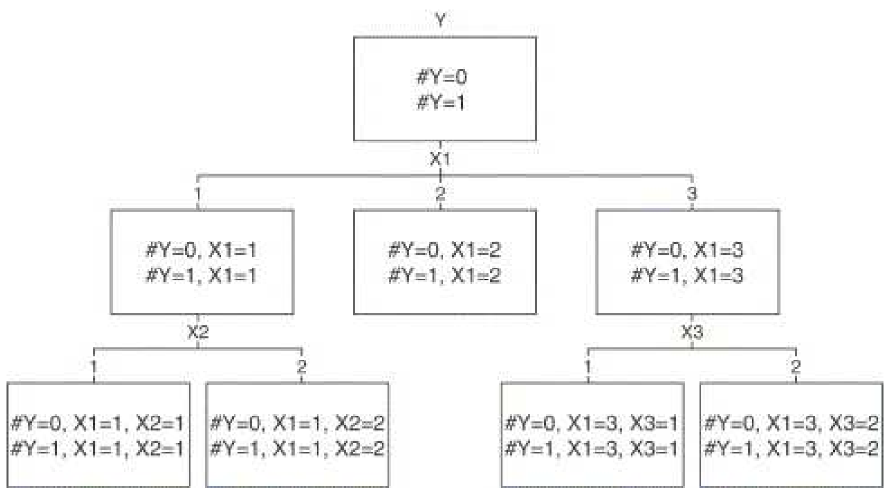


Figure 2-10. Example of N-ary tree in CHAID.

In essence, CHAID is used to construct n-ary (non-binary) trees, which for classification problems (when the dependent variable is categorical in nature) relies on the Chi-square test to determine the best next split at each step; for regression-type problems (continuous dependent variable) the program will actually compute F-tests. In other words, only nominal or ordinal categorical predictors are allowed; continuous predictors are first transformed into ordinal predictors before using the following algorithm. Specifically, after this Chi-square tests and F tests are done and their p values are calculated. If the p values are not statistically significant, then the algorithm merges the respective predictor variables (or categories in case of categorical data). If a statistical significance is observed then a split is made (see Figure 2-11).

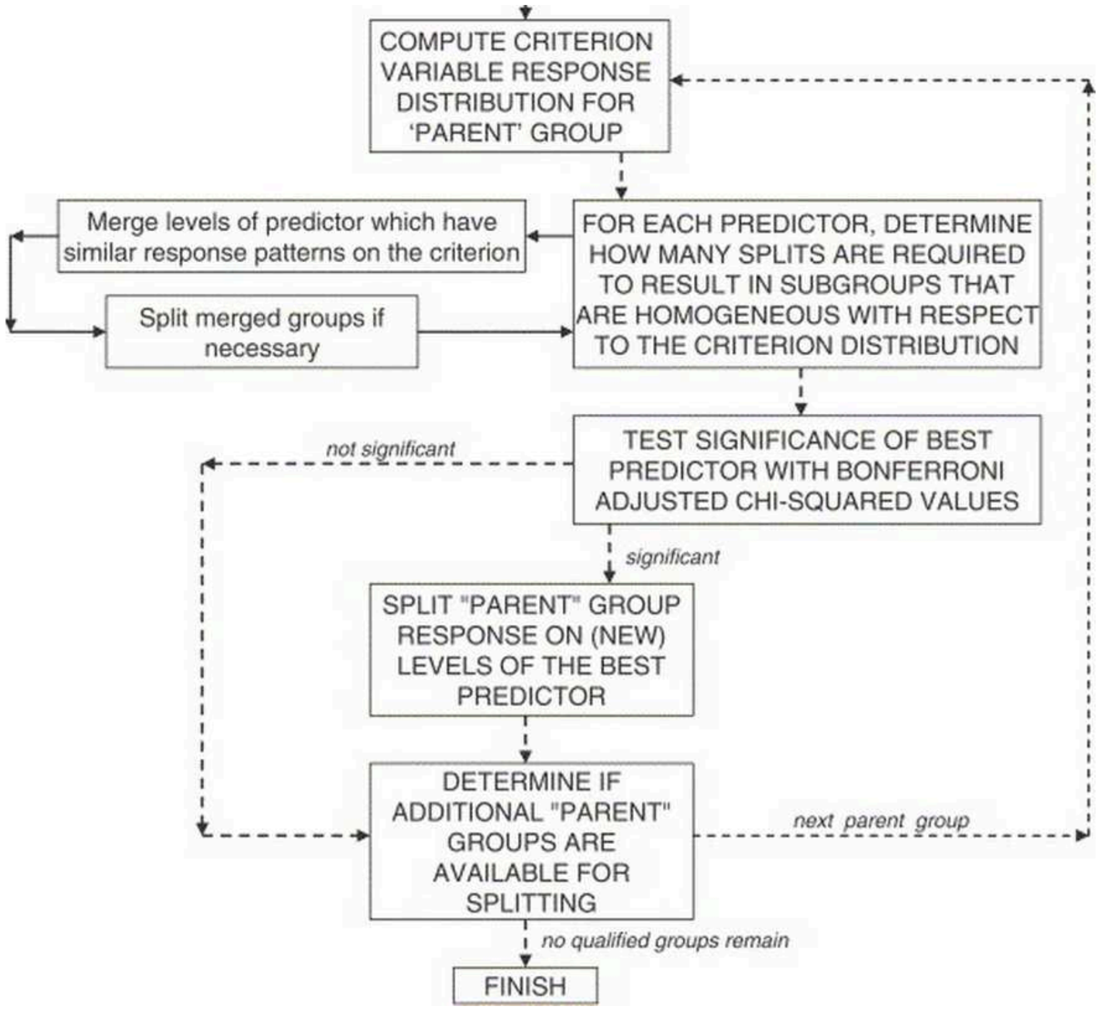


Figure 2-11. CHAID computing flowchart.

Source: van Diepen & Franses, (2006)

Gilbert (2010) suggested the most original contribution of CHAID is the optimal n-ary split for each predictor, and thus CHAID is currently the most popular among these earlier statistical supervised tree growing techniques. CHAID has also been used in the occupational safety and health (OSH) studies (Chi et al., 2012; D. A. Hill, Delaney, & Roncal, 1997).

Choosing CHAID as the method in this research is neither because it is fairly widely used (Tufféry, 2011) nor that it might perform better (Avilés-Jurado, Terra, Figuerola, Quer, & León, 2012), but that it is appropriate for this work. The author summarized major features of AID, CHAID, CART, QUEST and C5.0 in Table 2-1. Although all these techniques belong to classification trees, their differences are presented though the comparison on the listed features such as splitting criterion, split type, variable type, accuracy, and/or OSH application.

Table 2-1. Comparison among classification tree techniques.

	AID	**CHAID**	**CART**	**QUEST**	**C5.0**
Splitting criterion	BSS	X^2	Gini/twoing	twoing	gain
Split type	Binary	N-ary	Binary	Binary	N-ary
Splits per node	2	≥2	2	2	≥2
Variable type	O/I	N/O/I	N/O/I	N/O	N/O
Regression-type	Yes	Yes	Yes	No	No
Interaction detection	Yes	Yes	No	No	No
Unbiased splits	Yes	Yes	No	Yes	No
OSH adoption	Yes	Yes	Yes	No	No
Calculation speed	Normal	Normal	Normal	High	High
Accuracy	Normal	High	Normal	High	Normal
Misclassification costs	No	No	Yes	Yes	No

Note: N = nominal data; O = ordinal data; I = interval data.

Coupling the characteristics of the proposed data type and research objectives, CHAID is the preferred classification methods considering the following four primary features: split type, variable type, OSH adoption and accuracy.

Split Type

CHAID's n-ary splits can be conveniently summarized in a simple two-way table with multiple categories for each variables of dimension of the table. This type of display matches well the requirements for research on the proposed electrocution analysis. In contrast, CART or QUEST can only yield binary trees, which sometimes cannot be summarized as efficiently for interpretation and presentation (Shmueli et al., 2011; Tufféry, 2011; van Diepen & Franses, 2006).

As suggested by Hill and Lewicki (2006), CHAID is better suited for the explanatory task, whereas CART/QUEST is more suitable for prediction. In other words, CHAID should be used when the goal is to describe or understand the relationship between a response variable and a set of explanatory variables, whereas CART/QUEST is better suited for creating a model that has high prediction accuracy of new cases. This research focuses on the causation analysis on construction electrocution and, as a result, CHAID seems more appropriate.

Variable Type

The appropriateness of variable type is another important consideration for choosing CHAID. The proposed data source is The data source used in This research are from the Fatality Assessment and Control Evaluation (FACE) program by the National Institute of Occupational Safety and Health (NIOSH) professional investigators (NIOSH, 2010). FACE reports provide descriptions on hundreds of fatal occupational injuries through investigating work situations and disseminate prevention strategies since 1982. The nature of FACE reports is narrative text and the expected data type is primarily nominal data (categorical data). CHAID is advanced in the performance on analyzing categorical data and thus more appreciate for this research.

OSH Adoption

As mentioned in the previous section, CHAID has been applied in OSH area in the existing literature (Alfonso & Kaur, 2012; Delgado, Mata, Yepes-Baldo, Montesinos, & Olmos, 2013; Hartling, Pickett, & Brison, 2002; E. L. Murphy & Comiskey, 2013), which provide useful demonstration of this classification technique. Particularly, Chi et al. (2012) analyzed 250 electrical fatalities in the Taiwan construction industry and utilized CHAID to code the electrocution data to summarize a subset of predictor that might derive meaningful classifications or accident scenarios. Therefore, the widely applied CHAID within the OSH area is also believed to be appropriate for this research which emphasizes on construction OSH.

Accuracy

CHAID is believed to have comparatively high accuracy. For example, Chou (2012) compared the performances of many classification techniques (including CHAID, CART, QUEST and C5.0) for dispute methods in public-private partnership (PPP) projects, and found three best performing ones which are CHAID (83.82%), QUEST (82.99%), and C5.0 (82.57%). Of the three, CHAID has the highest performing accuracy at 83.82%.

In summary, compared to all aforementioned classification techniques, CHAID is the best available for the propose study on construction electrocution.

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CHAPTER 3.
SOCIOTECHNICAL SYSTEMS OF FATAL ELECTRICAL INJURIES IN THE CONSTRUCTION INDUSTRY

Abstract: The construction industry experiences the greatest proportion of workplace electrical injuries globally. Much research effort has gone towards analyzing this phenomenon, a majority of which used descriptive methods often through computing frequencies. Although findings from such studies provided good summaries on accident characteristics and the contributory factors, they are often insufficient in explaining interactions within injury systems. To fill the gap, this work begins by analyzing NIOSH's FACE data (1989-2012) to explore the sociotechnical systems and reveals three representative patterns of fatal electrical injuries in construction. The work then examines the associations between personnel, technological, and organizational/managerial subsystems, and the internal and external environments in the three identified system patterns, mapping systemic weaknesses using a macroergonomics model (MM) framework. This work finally recommends corresponding injury intervention strategies. This work introduces a novel triangulation approach for injury analysis and intervention strategies grounded in the broad concept of workplace safety, namely organizational, social, political and psychological contexts.

Keywords: Sociotechnical system; Macroergonomics; Construction safety; Electrical injury; Risk management; Latent class; Correspondence analysis.

3.1 INTRODUCTION

The Occupational Safety and Health Administration (OSHA) defines contact with electricity as one of the “fatal four causes” to occupational injuries. Among various industrial production sectors in the US, construction contains the highest percentage of electrocution and its workers encounter the highest risk from electrical injuries at work (Zhao, Thabet, et al., 2014). From 2004 to 2013, 47.1 % of fatal electrical injuries were from the construction industry (U.S. Bureau of Labor Statistics [BLS], 2014). Moreover, the disproportionate rate of electrical fatalities in construction exists globally, not just in the US (Higgins et al., 2001; Ling, Liu, & Woo, 2009; Suárez-Cebador, Rubio-Romero, & López-Arquillos, 2014).

Literature on the subject of electrical safety includes international efforts to investigate the nature of electrical injuries (Cawley & Homce, 2003; Janicak, 2008; Loomis, Dufort, Kleckner, & Savitz, 1999; McCann, Hunting, Murawski, Chowdhury, & Welch, 2003; Ore & Casini, 1996). A large body of the studies used descriptive methods, characterizing surveillance or census data (Cawley & Brenner, 2012; Huss, Vermeulen, Bowman, Kheifets, & Kromhout, 2013; Loomis et al., 1999; Zhao, Thabet, McCoy, & Kleiner, 2012). Findings from such descriptive approaches have provided good summaries about contributory factors such as occurrence time, victim demographics, worker activities, electrical sources, or working conditions. However, they are considered insufficient in explaining the risks of systems surrounding an accident. Univariate analysis ignore potential associations with other factors. As a result, factors are separated from the contextual system and may even produce insufficient conclusions (Depaire, Wets, & Vanhoof, 2008). For example, contributory injury factors such as “overhead power lines” (Janicak, 2008), which only exists in an outdoor environment, and “indoor workplace” (Sawacha, Naoum, & Fong, 1999) are incompatible, while often part of injury analysis, and thus cannot be simply combined to interpret real-world electrocution circumstance, even though each of them might have high frequency statistically. As Strauch (2002) highlighted, what ultimately differentiate factors are their contexts and the relative severity of their consequences. The nature of workplace systems and internal interactions demand a multidisciplinary systems approach to addressing safety improvements (Nagamachi &

Imada, 1992). Therefore, safety is an outcome of a work system with cooperative components where individual components do not bear all of the responsibility for keeping workers safe (Murphy, Robertson, & Carayon, 2014). A systems perspective covering electrical hazards, human behaviors, and incident circumstances is a necessity for examining electrical injuries.

A systems perspective considers sociotechnical system (STS) breakdown(s) as the essential contribution to accident occurrence (Hanninen & Kujala, 2012; Kleiner et al., 2008; Zhao, Thabet, et al., 2014). Sociotechnical system theory was empirically developed in the late 1940s and 1950s by Fred Emery and Eric Trist, and refined by Katz and Kahn (1966). Pasmore and Sherwood (1978) then characterized STS as organizationally complex that recognizes the interaction between human and technology in a work environment. Systems theory views the organization as an agency which transforms a variety of inputs into positive or negative outputs. It also highlights three elements within this transformative process: technological subsystem, personnel subsystem, and work system design consisting of an organizational structure and managerial processes. The three elements interact with one another and the external environment, on which the organization depends, for its survival and success. Thus, a systems perspective emphasizes sociotechnical associations within the contextual accident system. For example, Rasmussen (1997) identified an accident as a failure across six subsystems: government policy and budgeting; regulatory bodies and associations; local area government planning and budgeting technical and operational management; physical processes and actor activities; and equipment and surroundings; and Kleiner (2006) focused on the interactions in a sociotechnical system in terms of hardware and/or software, internal environment, external environment, and/or an organizational design. In analyzing electrical injuries, the adoption of a systems perspective might improve the understanding on accident system factors and their interactions that generate hazardous situations and shape worker behaviors (Arboleda & Abraham, 2004; Mitropoulos et al., 2005).

Adopting a systems perspective, this work addresses each electrical fatality as a dysfunctional sociotechnical system on a task level. Specifically, the work system is where an individual performs tasks using tools and technologies, and works in a physical environment that is under the control of an organization with its own policies, practices, and procedures (Murphy et al., 2014). Therefore, the objective of this work is to identify the breakdowns within such work systems in the construction industry by exploring the personnel, technological, organizational/managerial subsystems, the overall environments, and examine their multilateral interactions within the accident contexts. To maximize the validity and reliability of expected outcome, this work attempts to use both latent class analysis (LCA) and multiple correspondence analysis (MCA) techniques in parallel, then integrating findings into a macroergonomic model (MM) framework. Findings from this research will help to facilitate electrical injury intervention strategies grounded in a broader conception of workplace safety in the organizational, social, political and psychological contexts. Also, the novel triangulation approach introduced through LCA, MCA and MM contributes to the greater body of work in systems methodology in construction safety research and beyond.

3.2 DATA AND VARIABLES

Accident data were obtained from the National Institute of Occupational Safety and Health (NIOSH)'s Fatality Assessment and Control Evaluation (FACE) program for a period of 24 years (1989-2012). Only injuries due to electrocution and occurring in the construction industry were selected for this analysis. The final dataset contains 143 fatal injury records.

FACE data are narrative reports with a purpose of identifying conditions that increase the possibility of work-related fatal injury. FACE considers various factors contributing to an event in which a worker dies and summarizes them in the onsite investigation report. Compared to coded injury surveillance or census data, FACE reports contain non-routinely-analyzed data elements in the narratives (Bunn et al., 2008; Langley, 1995). These elements are helpful to revealing hidden interactions in the fatal injury systems.

A prior study from Zhao, Thabet, et al. (2014) conducted a descriptive analysis using 13 contributory factors pertaining to "when", "who", "when" and "how" of electrical accidents to examine the FACE investigations. As an extension of that study, this work uses 12 similar categorical variables to interpret the workplace sociotechnical system within the macroergonomic model framework. Table 3-1 gives an overview of all the 12 variables and their values. The variable set allows the researcher to reflect on the conditions that contributed to the accident system from the personnel subsystem (occupation, age, gender), technological subsystem (agent, electricity source), organizational/managerial subsystem (written safety policy, electrical safety training), internal environment (voltage, workplace), and external environment (season, workday).

Table 3-1. Variables and their values.

Variable Name	Value Code	Value description	System Aspect	Citation
Project	Prj_R	Residential building construction	Work system	NAICS 2012
	Prj_N	Non-residential building construction		
	Prj_H	Heavy and civil engineering construction		
Occupation	Ocp_E	Electrical workers	Personnel subsystem	SOC 2010
	Ocp_N	Non-electrical workers		
Age	Age_A	Adolescent (age<20)	Personnel subsystem	Erikson (1993)
	Age_Y	Young adult (age 20-39)		
	Age_M	Middle adult (age 40-64)		
	Age_O	Old (age>64)		
Gender	Gen_M	Male	Personnel subsystem	
	Gen_F	Female		
Agent	Agt_D	Directly contacting electrical source	Technological subsystem	
	Agt_I	Indirectly contacting electrical source through an agent (e.g., ladder, scaffold, aerial bucket, or pipe)		
Source	Src_P	Overhead or buried power lines as part of the utility system	Technological subsystem	CFOI
	Src_C	Electrical components (e.g., wirings, transformers, or panels)		
	Src_M	Powered machinery, tools, appliances, or equipment (e.g., crane, truck)		
Policy	Pol_Y	Has written safety policy.	Organizational/managerial subsystem	
	Pol_N	No written safety policy.		

Training	Trg_Y	Has safety training programs.	Organizational/managerial subsystem	
	Trg_N	No safety training programs.		
Voltage	Vol_H	High voltage (>= 1000 volts)	Internal environment	IEC 60038
	Vol_L	Low voltage (<1000 volts)		
Workplace	Wpl_O	Outdoor environment (physically outside a facility or structure)	Internal environment	
	Wpl_I	Indoor environment (physically inside a facility or structure)		
Season	Szn_Sp	Spring (March, April, May)	External environment	
	Szn_Sm	Summer (Jun, July, August)		
	Szn_F	Fall (September, October, November)		
	Szn_W	Winter (December, January, February)		
Workday	Wkd_K	Weekday (Monday to Friday)	External environment	
	Wkd_N	Weekend (Saturday and Sunday)		

NASCI: North American Industry Classification System;
SOC: Standard Occupational Classification;
CFOI: Census of Fatal Occupational Injuries;
IEC 60038: International Electrotechnical Commission standard.

3.3 METHODS

3.3.1 Latent class analysis

Latent classes (LCs) are unobservable (latent) subgroups or segments. Cases are homogeneous within the same latent class while distinctive from each other in different latent classes, depending on certain criteria (Vermunt, 2008). Latent class analysis (LCA) is a technique to identify the smallest number of latent subgroups or clusters that are sufficient to explain all the associations among manifest variables in a sample group. Technically, an LC is represented by K distinct categories/values of a nominal latent variable. Variables of LCA can be continuous or categorical. Lazarsfeld (1950) originally introduced the LCA method to explain response heterogeneity in a survey with dichotomous variables. Goodman (1974) then developed the maximum likelihood algorithm for LCA, and Vermunt (2008) extended it with finite mixture models for multivariate nominal data analysis. Recently, LCA is able to include mixed-scale-type variables and covariates, and thus has been adopted in a wide-range of research areas including accident analysis (L. M. Collins & Lanza, 2010; Depaire et al., 2008) .

Assume Y_n (n=1, 2, 3,…, N) represents one of the N observed variables and can be described by a set of values (y_{n1}, y_{n2}, … , y_{nm}), and assume X_k (k=1, 2, 3,…, K) represents a cluster from the LC model with K latent classes (named as LCM-K), the LC model for categorical variables (Vermunt, 2008) can be expressed as:

$$\boldsymbol{p(Y|\theta) = \sum_{k=1}^{K} p(X_k) p(Y|X_k, \theta_k)} \quad \text{(Equation 3-1)}$$

where θ_k is the unknown value vector for cluster X_k, $p(X_k)$ is the prior probability of cluster X_k ; $p(Y|X_k, \theta_k)$ is the conditional multivariate probability density; and $p(Y|\theta)$ is the mixture probability density for the whole data set. Particularly, this study uses 12 observed variables (N=12) while the goal of LCA is to identify the cluster X_k.

Every given cluster X_k has a underlying probability distribution, and when its distribution is known the problem of identifying the cluster X_k transfers to a problem of parameter estimation (Depaire et al., 2008). In other words, the estimation process evaluates LC models by assigning them different number of LCs (K=1, 2, …) until the best fitting model is obtained. The goodness-of-fit of estimated model is usually tested by the likelihood-ratio chi-squared statistic L^2 (Magidson & Vermunt, 2001), defined as:

$$\boldsymbol{L^2 = 2 \sum_{i=1}^{I} \left[n_i \times \log \frac{n_i}{\widehat{m}_i} \right]} \quad \text{(Equation 3-2)}$$

where I is the total number of possible cell entries in the N-dimensional frequency table; i is a particular cell entry in the contingency table; n_i is the observed frequency counts for cell entry i; and $\boldsymbol{\widehat{m}_i}$ is the estimated expected frequency count for cell entry i.

However, it is invalid to compare LC models with different number of LCs (e.g, models with K LCs and K+1 LCs) by directly calculating the discrepancy of their L^2 values (or the degree of freedom df values) due to distribution (Hagenaars & McCutcheon, 2002). As a result, alternative methods are required to identify the best fitting model (i.e, the best number of K). This study uses three information criteria to evaluate the goodness-of-fit, which are the Bayesian information criterion (BIC), the Akaike information criterion (AIC), and the consistent AIC (CAIC). Based on computation using L^2 and *df* values, these information criteria measure an LC model's parsimony. Often, a lower criteria value indicates a higher parsimony and suggests a better model fitting. For example, an LC model with a lower BIC value is preferred rather than one with a higher BIC value.

3.3.2 Multiple correspondence analysis

Another paralleled analysis method used in this research is the multiple correspondence analysis. MCA is an exploratory multivariate technique for graphically display the homogenous patterns of rows or columns in a multi-dimensional contingency table (Greenacre & Blasius, 2006). The goal of using MCA is to produce a visualized diagram in which homogenous variable values (see the list of values in Table 3-1) are plotted close together and heterogeneous values are plotted far apart. As a result, vicinal plots (representing values) in a MCA diagram can be classified into a homogeneous subgroup and considered as a pattern.

MCA is an appropriate technique for exploring relationships among variable values especially when the variables are categorical (Sourial et al., 2010). Specifically, the researchers chooses MCA in this study primarily because of two merits: (a) it allows researchers to explore associations of values across different variables, and (b) also allows to examine multiple categorical variables simultaneously. For more information on MCA and its application in health and safety research, please refer to these studies (Conte et al., 2011; Ferrante, Marinaccio, & Iavicoli, 2013; Lu et al., 2012).

3.3.3 Macroergonomic model framework

The macroergonomic model, following established sociotechnical system theories, is a framework for explaining the relations and interactions among personnel subsystem, technological subsystem, organizational/managerial subsystem, and internal and external environments (see Figure 3-1). Hendrick and Kleiner (2002) developed a macro-level sociotechnical model, termed macroergonomic analysis and structure (MAS), for analyzing work systems. MAS involves two or more people interacting with some form of: hardware and/or software; internal environment; external environment; and an organizational design. Hardware typically refers to tools, equipment, machines, workspaces, and buildings while software is management-based policies, rules, procedures and/or manuals (Murphy et al., 2014). Kleiner (2006) then refined MAS processes into macroergonomic analysis and design (MEAD), highlighting ten specific steps in evaluating work systems. MM in this work, and shown in Figure 3-1 below, was built upon the above studies and has been broadly applied as a framework in research for organization design and system optimization (Carayon, Sainfort, & Smith, 1999; Guimarães, Ribeiro, Renner, & de Oliveira, 2014; Nagamachi & Imada, 1992). Compared with micro-level human factors (e.g., human-machine interface) engineering, MM focuses on organizational design, process evaluation and change management in a higher bird view on a macro-level. It is integrative in that it focuses on the entire organization by utilizing knowledge, methods, and tools from a number of research areas, including sociotechnical systems, industrial/organizational psychology, cognitive ergonomics, physical ergonomics, systems engineering, and social psychology (Murphy et al., 2014)

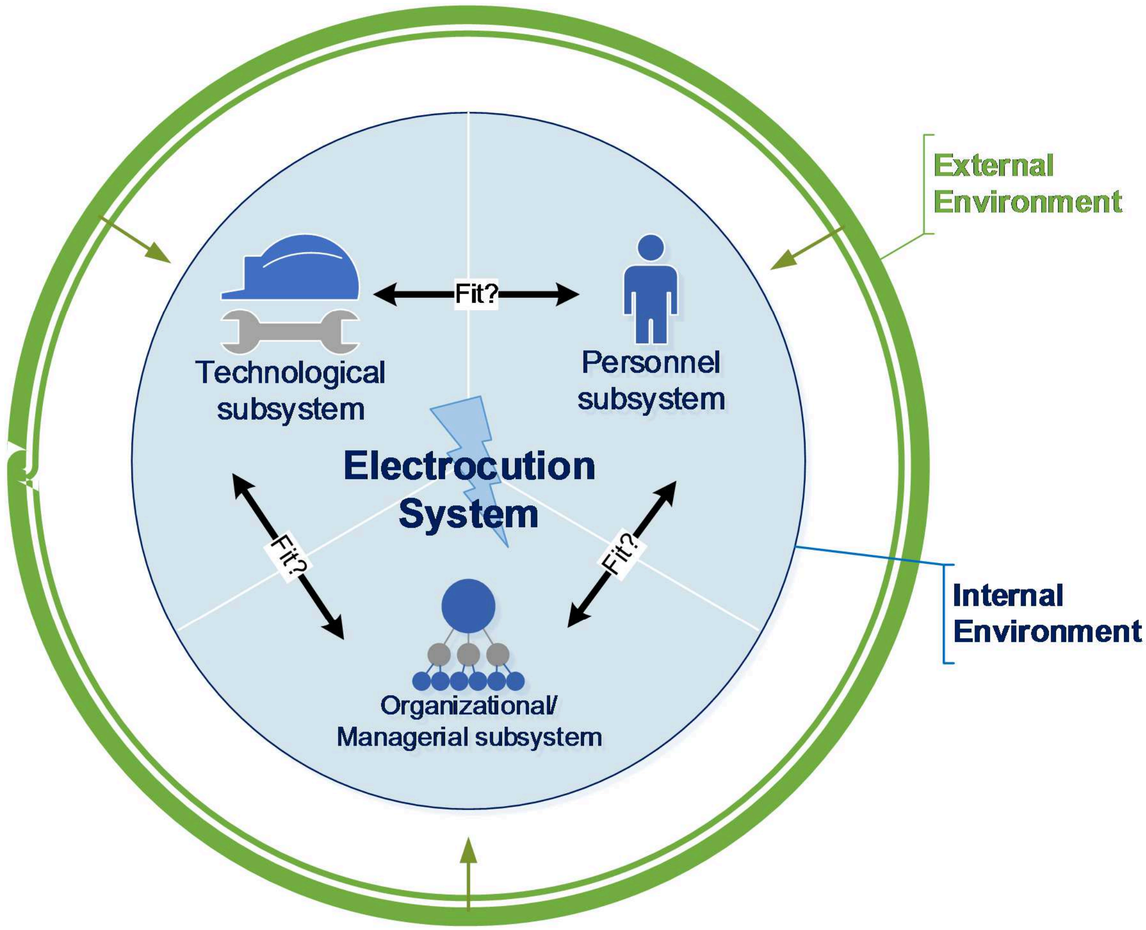

Figure 3-1. Macroergonomic model of electrocution system.

Other than organization design and systems optimization, MM also provides a framework for the diagnosis of system failures and the improvement of construction safety (Kleiner, 1999; Kleiner et al., 2008; Murphy et al., 2014; Robertson, Schleifer, & Huang, 2012). It recognizes that accident events occur as a result of people interacting with systems at physical and cognitive levels within a sociotechnical system that can amplify, limit or nullify human factors or interventions that change a condition (Nagamachi & Imada, 1992). As suggested by Haro and Kleiner (2008), the macroergonomic model provides a comprehensive framework for analyzing system safety in the construction industry, which includes an understanding of technology, personnel, external environment, internal environment, organizational and management structure and the interactions between them.

In such a macroergonomic model (see Figure 3-1), the three subsystems influence each other within the internal environment; the external environment does not directly but indirectly influences the work system through its impact on the internal environment (green arrows in Figure 3-1). When adopting the MM framework for system evaluation, two rules should be followed: (1) all subsystems interact - any change in one will affect others; (2) bilateral breakdowns between any two subsystems may result in safety problems. Through this method, "fits" between two subsystems in a certain context can be assessed. The criteria of a "fit" can be physical, psychological, social, cultural, or philosophical in nature.

3.3.4 Triangulation Approach Merits

A triangulation approach using LCA and MCA analysis techniques, then incorporated into the MM framework is innovative for examining safety sociotechnical systems for construction electrocutions.

LCA and MCA are mathematically related but have independent algorithms. The goal of using them in this work is to identify the representative fatal electrical injury patterns and their latent value sets. Also, MCA has another merit of graphically displaying the relationship of all variables in a single two-dimensional plot. More information about the MCA's algorithm is available from Greenacre and Blasius (2006). The details on the two techniques' similarities and differences are available from Van der Heijden, Gilula, Der Ark, and Andries (1999).

MM, as an STS framework, reinforces the notion that problem elements are linked, related and are reactive even while being isolated in a social-technical system. At its core, MM reveals deeper relationships and interactions. The goal of using macroergonomics model in this work is to scan the electrical injury system, as shown in Figure 3-1, and identify contextual variables, and meanwhile to evaluate the "fits" between subsystems: personnel, technological and organizational/managerial under specific internal and external environments.

Such a comprehensive method aims to increase research validity and reliability as well. Research validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure while reliability is the extent to which any measuring procedure yields the same result on repeated trials. The adoption of two parallel analyses, LCA and MCA, aims to verify and complement analysis results for each other, increasing validity. Meanwhile, the integration of an MM framework aims to contribute to evaluating and interpreting workplace systems within real-world contexts, detecting fatality causations consistently across contexts.

3.4 RESULTS

3.4.1 Latent class analysis

In this study, the researchers puts all variables shown in Table 3-1 into the latent class analysis, except of the variable *Gender* with value Gen_M and Gen_F. This exception is due to the fact that all victims from the dataset were male. As a result of LCA requirements, the analysis process removes the two values.

To find the best model fit, the author attempted to assign the LC model with increasing numbers of LCs (*K*), starting from 1 (*K* =1, 2, …), and named the models LCM-1 (*K*=1), LCM-2 (*K*=2), … This work then evaluated the goodness-of-fit of these LC models by comparing their information criteria values. The three information criteria used in this work (previously described in the methods section) are BIC(L^2), AIC(L^2) and CAIC(L^2), a lower value of which suggests a better model fitting. The results of model fitting evaluation are demonstrated in Figure 3-2, suggesting LCM-3 (*K*=3) contains the best goodness-of-fit (lower BIC, CAIC). When the number of LCs grows greater than 3, the information criteria (especially BIC, CAIC) values indicate little additional improvement of fitting. In addition, LCM-3's *p*-value of 0.056 (good when greater than 0.05) and *Npar* value of 50 (the number of parameters) also indicate a good separation between latent classes.

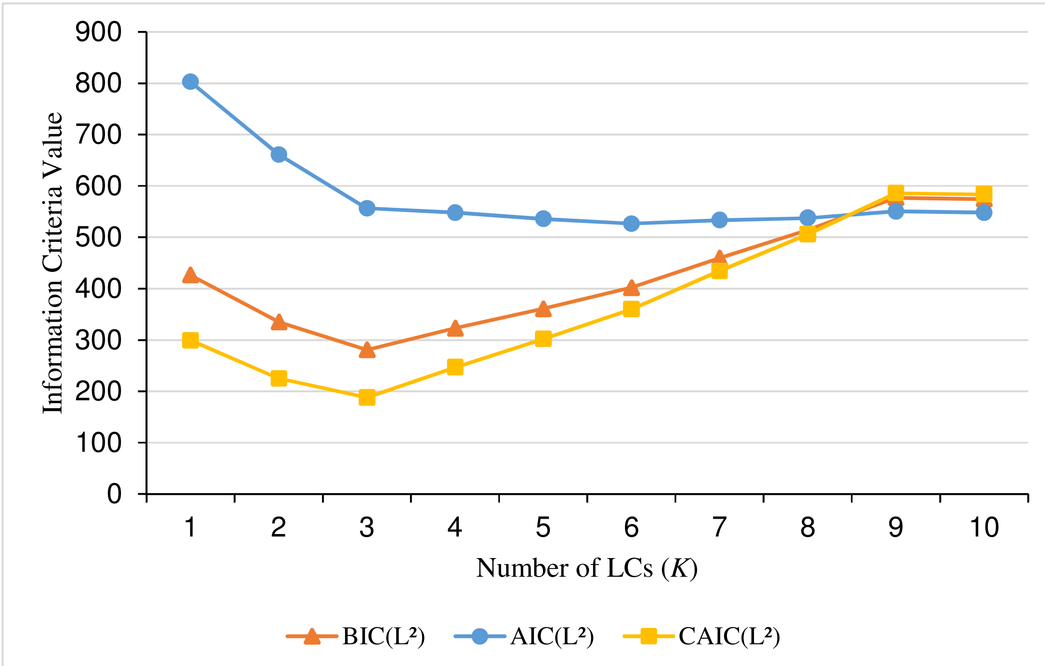

Figure 3-2. LC model fitting results.

LCM-3 (K=3) provided LC-dependent univariate distributions for each variable, allowing each of the three latent classes (LC#1, LC#2, and LC#3) to represent a typical electrocution system pattern. In LCM-3, the probabilities of falling into LC#1, LC#2, and LC#3 (see $p(X_k)$ in equation 3-1) are 41%, 36%, and 23%, respectively. To identify specific value vectors (θ_k, k=1, 2, 3), the researcher examined the probability of falling into a certain LC for every particular variable value. The probability indicates the degree of correlation between a value and a designated LC. In multivariate statistical analysis, some research (Stevens, 2002) preferred a cut-off of 0.4 for important loading while some other (Kline, 1994) suggested 0.3 as an acceptable threshold, irrespective of sample size. Here, this work chooses a probability of 0.35 (the average of 0.3 and 0.4) or greater to determine a closer correlation between a variable value and the corresponding LC in LCM-3 (the bold in Table 3-2). As a result, three significantly related value vectors (θ_k) to each of the three LCs are identified, alphabetically listed as follows:

- Value vector θ_1: Age_A, Age_Y, Agt_I, Ocp_N, Pol_N, Prj_R, Src_M, Src_P, Szn_Sm, Szn_W, Trg_N, Vol_H, Wkd_K, Wkd_N, and Wpl_O.
- Value vector θ_2: Age_M, Agt_D, Ocp_E, Pol_Y, Prj_H, Src_C, Src_P, Szn_F, Szn_Sp, Szn_W, Trg_Y, Vol_H, Wkd_N, and Wpl_O.

- Value vector θ_3: Age_A, Agt_D, Prj_N, Src_C, Src_M, Vol_L, and Wpl_I.

Table 3-2. Variable value's probabilities of falling to LCs in LCM-3.

Variable Value	Probability of falling to		
	LC#1	LC#2	LC#3
Prj_R	**0.6949**	0.0171	0.2881
Prj_N	0.2693	0.2686	**0.4621**
Prj_H	0.2889	**0.6459**	0.0652
Ocp_E	0.1126	**0.6087**	0.2788
Ocp_N	**0.6418**	0.1610	0.1972
Age_A	**0.3882**	0.1999	**0.4119**
Age_Y	**0.4681**	0.3263	0.2056
Age_M	0.3071	**0.4474**	0.2455
Agt_D	0.0648	**0.5395**	**0.3957**
Agt_I	**0.6355**	0.2371	0.1275
Src_P	**0.5886**	**0.3719**	0.0395
Src_C	0.0316	**0.4501**	**0.5183**
Src_M	**0.4285**	0.1918	**0.3797**
Pol_Y	0.1126	**0.6787**	0.2088
Pol_N	**0.6832**	0.0626	0.2542
Trg_Y	0.1565	**0.6002**	0.2433
Trg_N	**0.6074**	0.1683	0.2244
Vol_H	**0.5400**	**0.4568**	0.0032
Vol_L	0.0023	0.0326	**0.9651**
Wpl_O	**0.5357**	**0.3821**	0.0822
Wpl_I	0.0000	0.2674	**0.7326**
Szn_Sp	0.3342	**0.4520**	0.2139
Szn_Sm	**0.5095**	0.1749	0.3156
Szn_F	0.3129	**0.4942**	0.1929
Szn_W	**0.5064**	**0.4936**	0.0000
Wkd_K	**0.4029**	0.3332	0.2639
Wkd_N	**0.4780**	**0.5219**	0.0000

It is noteworthy that the three values of variable *Project* (Prj_R, Prj_N, and Prj_H) are coincidently allocated into LC#1, LC#3, and LC#2, respectively. It implies that LC#1 is highly correlated to the residential building construction projects; LC#2 is highly correlated to the heavy and civil engineering construction projects; and LC#3 is highly correlated to the non-residential building construction projects. The LCA results (Table 3-2) can also be interpreted in a tri-plot diagram (see Figure 3-3), showing each LC's characteristics in a more visual manner(Magidson & Vermunt, 2001). In the diagram, the three vertices indicate the three LCs while the distance between any two points reflects their relationship (the shorter, the closer). For example, the plot of value Vol_L is geometrically close to LC#3 (on the top of the diagram), suggesting a great probability of falling into LC#3. Also, the distance between plots of Ocp_E and Trg_Y is relatively short, which suggests that "electrical workers" have high probability of "being trained". The small blue triangle symbol inside the tri-plot is the centroid of the bigger triangle, marking the overall probabilities of clusters associated with the vertices.

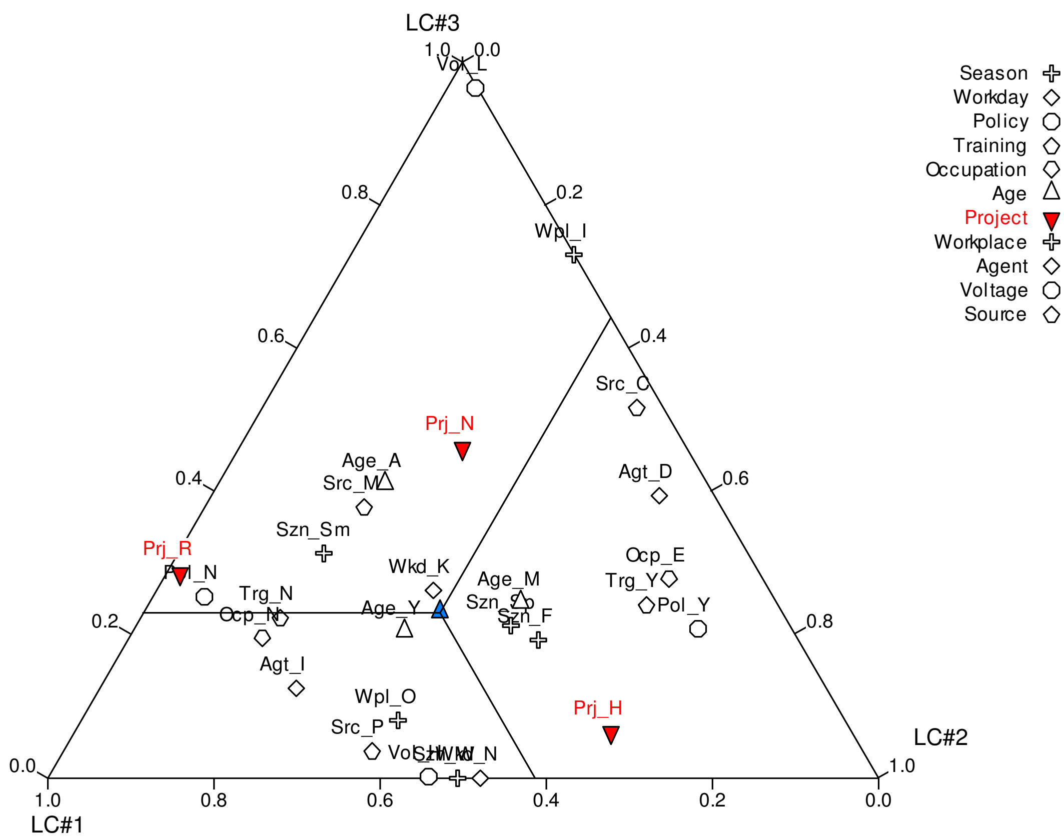

Figure 3-3. Tri-plot of LCA results.

In conclusion, findings from LCA analysis fit into the following three representative electrocution system patterns with summarized characteristics:

LCA_Pattern#1: younger (age<40) male non-electrical workers die due to indirectly contacting high-voltage power lines or powered machines/tools, usually in Summer or Winter at outdoor workplaces. The employers do not have written safety policies nor provide safety training programs. This pattern is particularly related to the residential building construction projects.

LCA_Pattern#2: middle-aged (age 40-64) male electrical workers die due to directly contacting high-voltage power lines or electrical components, usually in Spring, Fall or Winter weekends at outdoor workplaces. The employers have written safety policies and provide safety training programs. This pattern is particularly related to the heavy and civil construction projects.

LCA_Pattern#3: adolescent (age<20) male workers died due to directly contacting low-voltage electrical components or powered machines/tools at an indoor workplace. Whether the employer has written safety policies or provides safety training programs is uncertain. This pattern is particularly related to the non-residential building construction projects.

3.4.2 Multiple correspondence analysis

This work then mapped MCA results through a two-dimensional display, as shown in Figure 3-4. The eigenvalues for the first two-dimensional axes were 2.99 and 2.26. In such a plot, points close to each other are similar with regard to the pattern of relative frequencies across the columns or rows in a contingency table. The row or column points are positioned in a manner that retains all, or almost all, of the information about the differences between the rows or columns. In this regards, the high-quality points, rather than principle axes, provide useful information to interpret the results in the MCA plot (Lu et al., 2012).

When examining the points in the MCA plot, three subgroups of homogeneous values (see ellipses in Figure 3-4) emerge in which the distances are relatively closer. As a result, the variable values are grouped into the following (in alphabetical order):

- Subgroup#1 (see right-side ellipse in Figure 3-4): Age_Y, Agt_I, Ocp_N, Pol_N, Prj_R, Src_M, Src_P, Szn_Sm, Trg_N, Vol_H, Wkd_K, and Wpl_O.
- Subgroup#2 (see bottom ellipse in Figure 3-4): Age_M, Agt_D, Ocp_E, Prj_H, Pol_Y, Szn_F, Src_P, Szn_Sp, Szn_W, Trg_Y, Vol_H, Wkd_N, and Wpl_O.
- Subgroup#3 (see left-side ellipse in Figure 3-4): Age_A, Prj_N, Src_C, Vol_L, and Wpl_I.

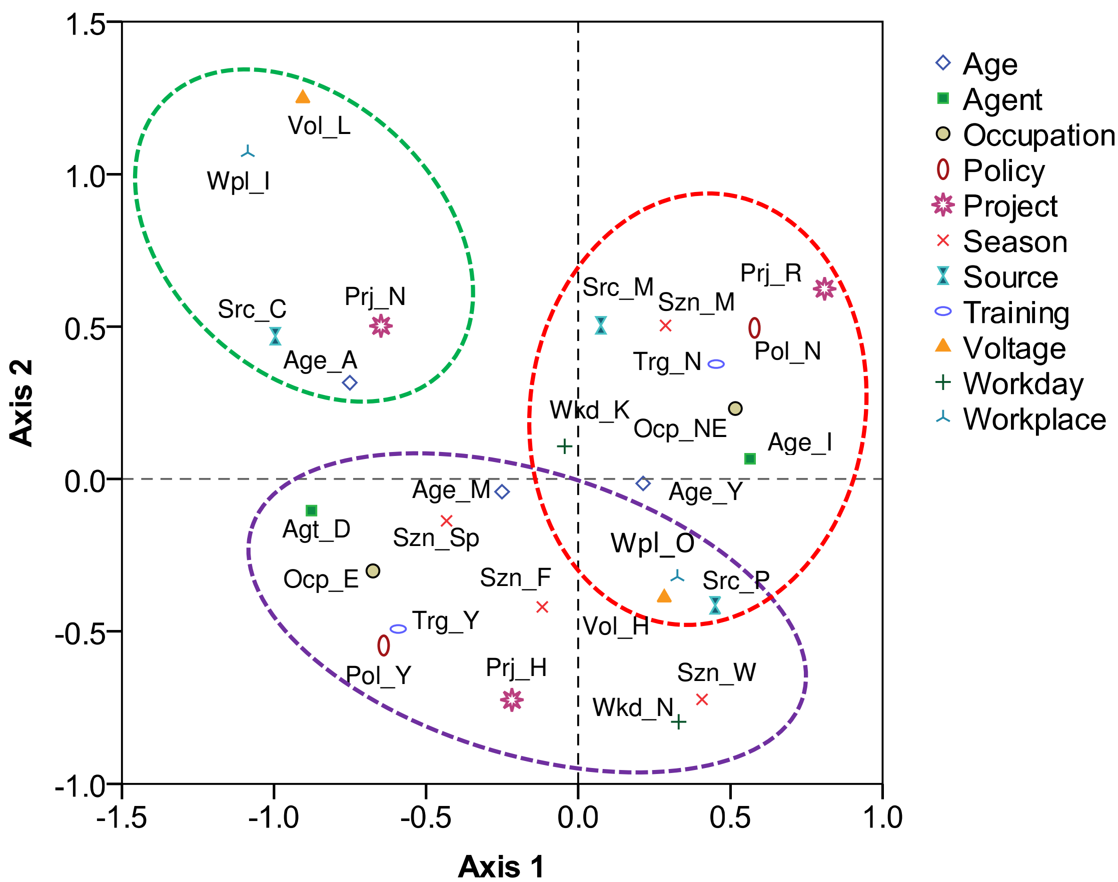

Figure 3-4. Multiple correspondence analysis plot.

Similar from LCA, the author organizes the three groups of values, resulting from MCA analysis, into the following three representative electrocution system patterns with summarized characteristics:

MCA_Pattern#1: younger (age 20-40) male non-electrical workers die due to indirectly contacting high-voltage power lines or powered machines/tools, usually in Summer weekdays or weekends at outdoor workplaces. The employers do not have written safety policies nor provide safety training programs. This pattern is particularly related to the residential building construction projects.

MCA_Pattern#2: middle-aged (age 40-64) male electrical workers die due to directly contacting high-voltage power lines, usually in Spring, Fall or Winter weekends at outdoor workplaces. The employers have written safety policies and provide safety training programs. This pattern is particularly related to the heavy and civil construction projects.

MCA_Pattern#3: adolescent (age <20) male workers died due to contacting low-voltage electrical components, usually at indoor workplaces. Whether the employer has written safety policies or provides safety training programs is uncertain. This pattern is particularly related to the non-residential building construction projects.

3.5 SYSTEM EVALUATION AND DISCUSSION

This work identifies three electrocution patterns from LCA and three from MCA which mutually confirm each other and show high consistency. Coupling the findings, the research and analysis reveals three representative system patterns of the fatal electrical injury in the construction industry. Interestingly, uncovered patterns correspond to three construction project types as well: residential, non-residential, and heavy and civil construction. The next section discusses interactions within the three electrocution patterns by further evaluating and integrating "fits" within the macroergonomics framework (previously shown in Figure 3-1).

3.5.1 Residential building construction

Figure 3-5 illustrates the sociotechnical system of fatal electrical injuries, largely for residential building construction projects. Based on MM, results focus on system weaknesses through three negative interactions. First, the interaction between the personnel subsystem and the organizational/managerial subsystem is a weakness. The lack of safety training exposes the non-electrical construction workers to the high-voltage electrical hazards. The victims are not electricity-related workers and thus do not have professions dealing with electrical hazards. The occupation includes construction laborers, roofers, masons, painters, and frame installers. To the younger workers who do not have sophisticated experience, even basic injury control and safe-practice training is critical. Second, the interaction between the technological subsystem and the organizational/managerial subsystem is another weakness. The lack of a written safety policy may fail to regulate the safe-working procedures especially for the non-electrical tasks. Even for non-electrical workers, standard injury prevention procedures, such as a field-level electrical hazard assessment, need to be established and enforced. Third, the internal and external environment may be a threat to the system. The external environment (e.g., severer weathers in summer or winter) directly impacts the outdoor jobsite conditions, coupling both of which may change the work climate, putting additional physical and psychological loads to the workers. For example, the high temperature and fierce sun glare may cause less concentration or lower awareness of workers to electrical hazards such as overhead power lines in an open area.

Nevertheless, uncertainties in associations exist within this pattern of results from this work and are insufficient to explain causation of injury. One uncertainty is the association between the personnel subsystem and the technological subsystem. The non-electrical workers should never be blamed, not to mention have little or no electrical skills. Another uncertainty is the impact from the work schedule (variable "*workday*") as this pattern includes both weekdays and weekends.

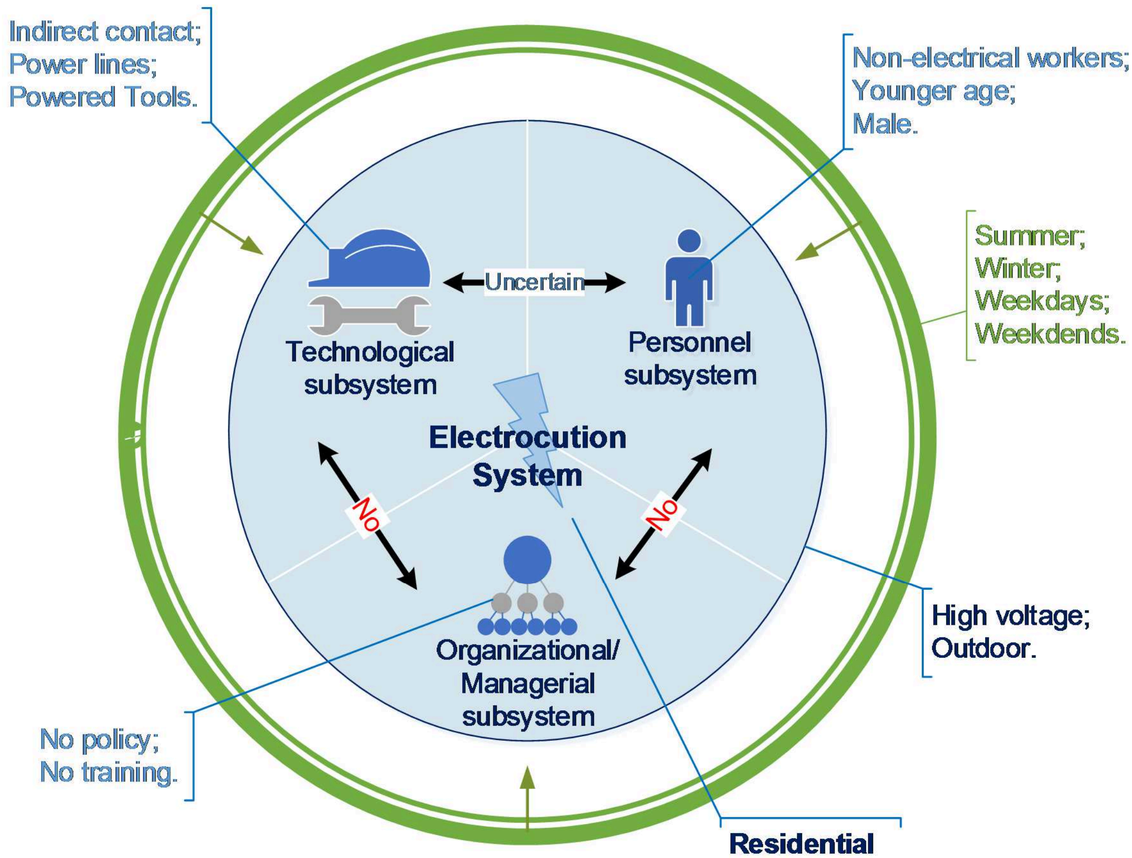

Figure 3-5. Fatal electrical injury system for residential construction.

Overall, the author- would argue that the primary system flaw in residential construction is the organizational and managerial subsystems. This argument is reflected in the reality of a majority of the residential construction firms being small-scale with less than 20 employees (Zhao, Thabet, et al., 2014). Coupled with low overhead, the cost for safety training and safety enhancement can seem unaffordable to small residential firms, even though OSHA requires basic safety training and awareness for all construction workers. Furthermore, the comparatively high mobility of the construction labor market may increase per-employee training expenses and thus some employers are not willing to spend the money on training an employee who might just stay for a few months. To address system weaknesses, the researcher- suggests ways that could lower managerial cost for resource-restricted smaller firms. One way is internet-based and open source material, such as free safety training documents and videos. Also, onsite hazard analysis needs to be emphasized by small firms as a fundamental policy for workplace safety. Again, free guidelines and forms for hazard analysis procedures are available on the internet. From a hierarchy of control perspective, these resources are administrative interventions. Outside of the injury system, some long-term external measures may also be helpful: (a) the government may provide financial support through tax deductions or worker-based subsidies for safety training; (b) related policy makers may provide standard safety policies and detailed practice procedures for more specific occupations (e.g., construction laborers); and (c) third parties, such as unions and/or training institutions, could provide more sophisticated, but lower-cost, best-practice training for electrical hazard recognition and accident avoidance.

3.5.2 Heavy and civil engineering construction

Figure 3-6 illustrates sociotechnical systems of electrical fatalities, largely for heavy and civil engineering construction projects. Weaknesses are explained through two negative interactions. One is the weak interaction between the personnel and technological subsystems. Such a pattern is surprising because experienced (middle aged) electrical professionals are being electrocuted by directly contacting power lines or powered machinery or equipment. According to the FACE narratives, one possible reason is the misjudgment of active power lines as de-energized due to a lack of effective communication. Another possibility is imperfect or even faulty equipment or tools. For example, aerial buckets or even some personal protective equipment (PPE) such as fall protection harnesses might touch live power lines by accident and cause electrocution.

A second negative interaction is the threat from the environment, which is similar to residential construction. The cold/wind and outdoor physical environment may influence safe work climate, especially pertaining to electrical hazard awareness, as electricity is invisible and requires more precautions. It is understandable that some heavy and civil projects (e.g., highway construction) have tight schedules and need to work on weekends or overtime. However, other relevant units (e.g., utility company, or infrastructure department) do not work at that time, which may lead to difficulty in collaboration. For example, it is often difficult to coordinate with employees from a utility company during weekend hours, even if deactivating power lines is needed. In addition, although the employers do have written safety policies and provide safety training programs, positive interactions between the organizational subsystem and the other two subsystems does not necessarily imply an effectiveness of training. In other words, the quality of organization and management, as a direct cause of electrocution, is beyond the scope that this work can address.

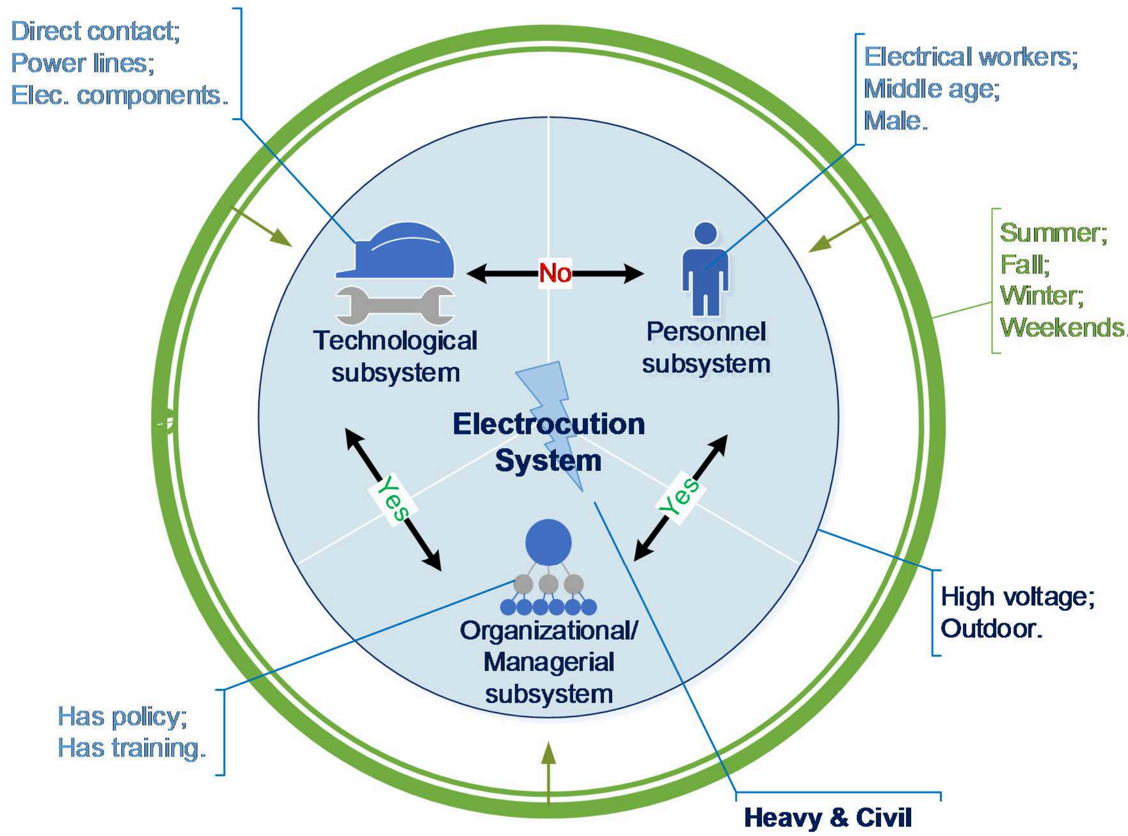

Figure 3-6. Fatal electrical injury system in heavy & civil engineering construction

Overall, this research highlights weaknesses in the technological subsystem of heavy construction projects, which suggest a need for corresponding administrative and engineering interventions. For example, the lockout/tagout rule requires strict procedures be followed and the communication among many workers of a crew and related third-party correspondents requires such procedures are communicated across the organization at all times. Engineering innovations may also improve the technological conditions. For example a safer portable device for testing high voltage electricity, the sensor and alert device on booms for detecting power line radiation, or the augmented video walkie-talkie for better crew communications could help improve safety. It is also noted that any technological preventions may change an existing work system and require corresponding adjustments from other subsystems. For example, if an innovative PPE is used in the workplace, the organizational subsystem should add the PPE into its training content and the personnel subsystem should select qualified workers who master how to use the equipment. As a result, the entire work system will need to be changed and another round of system evaluation is needed.

3.5.3 Non-residential building construction

Figure 3-7 demonstrates the fatal electrical injury system for non-residential building construction. Results highlight a weakness in the interaction between the personnel and technological subsystem. Psychological theory of human development (Erikson, 1993) underscored that adolescent workers (age<20) lack experience and are more likely to take risks for granted. Many adolescents do not perceive their actions as unsafe and often choose periodic activities with greater risk (Cohn, Macfarlane, Yanez, & Imai, 1995). Risk-taking behaviors from both young electricians and other workers could be a major cause of the electrocution by directly contacting low-voltage electrical components.

Previous studies argued that indoor working environments may reduce injury risk while lighting levels must be adequate inside a facility. Existing PPE are also capable of protecting workers from low-voltage electrical hazard if worn properly in such environments. Hence, the researcher proposes internal environments as an opportunity, as opposed to a threat, in the non-residential work system. As previously observed in other sectors of the construction industry, interactions with the organizational and managerial subsystem were uncertain for non-residential as well.

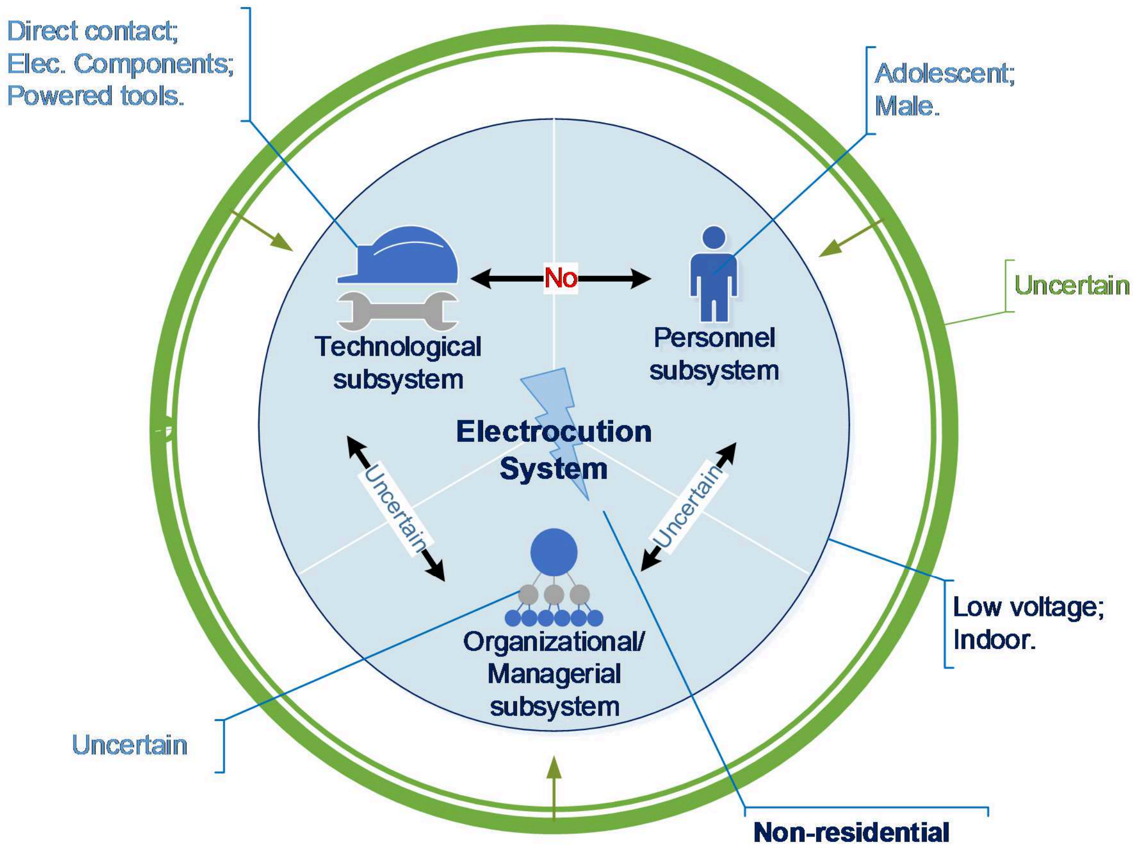

Figure 3-7. Fatal electrical injury system in non-residential building construction

Overall, the largest weakness of non-residential building projects (e.g., commercial construction, industrial construction, or institutional construction) results from the personnel subsystems. Consequently, substitutions and administrative interventions could offer remedial measures. For example, choosing a crew with an experienced mentor may contribute to hazard mitigation. People should note that the introduction of on-the-job mentorship or apprenticeship could create additional cost. Nevertheless, the balance of safety intervention and economic drivers is an important one for risk management in construction organizations. Safe procedures, such as GFCI testing, lockout/tagout, and the proper use of temporary wirings, need to be enforced in the workplace.

3.6 Conclusions

The construction industry contains the greatest proportion of workplace electrical injuries globally. Much research effort has gone to analyzing this phenomenon, with a majority using descriptive methods, and often through computing frequencies. Although findings from such studies have provided good summaries on accident characteristics and the contributory factors, they are insufficient for explaining interactions within the hazard system. To fill the gap, this work: analyzed NIOSH's FACE data (1989-2012) using latent class analysis (LCA) and multiple correspondence analysis (MCA) to identify the sociotechnical system (STS) of fatal electrical injuries in construction; evaluated the interactions between the personnel, technological, organizational/managerial subsystems, and internal and external environments through mapping out the system breakdowns with the help of macroergonomic model (MM) framework; and finally recommended corresponding injury intervention strategies.

Findings from this work reveal three representative electrical injury STS patterns and their system weaknesses. First, for residential construction, younger (age<40) male non-electrical workers die due to indirectly contacting high-voltage power lines or powered machines/tools, usually in Summer or Winter at outdoor workplaces. Employers often do not have written safety policies nor provide safety training programs. In this hazard system, organizational/managerial subsystem and its interactions with the other two subsystems have been identified as weaknesses while the internal and external environment is a threat. Based on the hierarchy of control, findings suggest a need for relevant administrative interventions.

Second, for heavy construction, middle-aged (age 40-64) male electrical workers die due to directly contacting high-voltage power lines or electrical components, usually in Spring, Fall or Winter weekends at outdoor workplaces. These employers typically have written safety policies and provide safety training programs. In this STS, technological subsystem and its interaction with the personnel subsystem are considered as weaknesses while the environment is a threat. Findings suggest a need for relevant engineering and administrative prevention measures.

Third, for non-residential construction, adolescent (age<20) male workers died due to directly contacting low-voltage electrical components or powered machines/tools at an indoor workplace. Personnel subsystem and its interactions with the technological subsystems are weaknesses. Findings suggest a need for substitution and administrative controls.

Outside of identifying three sociotechnical systems of electrical injury, this work also contributes to the body of knowledge by introducing a triangulation approach which integrates LCA and MCA techniques into the MM framework. This approach is applicable to other safety research in the construction area and beyond.

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CHAPTER 4.
DECISION-MAKING CHAINS IN ELECTRICAL SAFETY FOR CONSTRUCTION WORKERS

Abstract: Electrocution is among the critical four leading causes of worker deaths in the construction sector and thus it is paramount to identify the electrocution mechanisms and causation. This work interprets the mechanisms of an electrical accident as a chain of decision mistakes throughout the entire workplace. Due to construction's "one-off" nature, the researcher attempted to narrow the decision-making chain for a specific "feature of work" (FOW), a group of distinctive activities possessing higher OSH risks and requiring particular attention. The researcher analyzed 144 FACE investigation reports using Exhaustive CHAID and IDEF-0 techniques. Findings identify five features of work, illustrate their decision-making chains, and suggest critical decision-making points and constraints. This work promotes electrical safety for construction workers through the lens of decision making, and also contributes to the scholarly body of knowledge by introducing a comprehensive decision-making approach which is applicable to other safety research.

Keywords: Decision making; Feature of work; Occupational safety and health; Electrical safety; Decision-tree; CHAID; IDEF-0.

4.1 INTRODUCTION

Electrocution is among the critical four leading causes of worker deaths on construction sites, according to the Occupational Safety and Health Administration (OSHA). Data from the Bureau of Labor Statistics (BLS) (2014) show- that the “Fatal Four” were responsible for 58.7% of fatal construction work injuries in 2013, which means that eliminating the fatal four would save 468 workers' lives in the United States every year. The data also show that 51.1% of overall electrical fatalities occurred in the construction sector.

Literature highlights that these incidents are preventable because electrical hazards are understood by workers and could be controlled by adopting known interventions (Kleiner et al., 2008; Zhao & Lucas, 2014). A primary part of such risk reduction intervention is to identify accident mechanisms and causation in terms of occupational safety and health (OSH). The Swiss cheese model (Reason, 2000, Figure 4-1 below), prevalent in risk management, provides a tool for examining accident causation. The model proposes that there are many defending layers, like slices of cheese, between a hazard and the final failure. The final failure occurs when a hole in each slice momentarily aligns, permitting “a trajectory of accident opportunity” for a hazard to pass through holes in all of the slices. Following the same logic, the researcher interprets the occurrence of an OSH fatality as a series of choice mistakes in a decision-making chain throughout the entire workplace process.

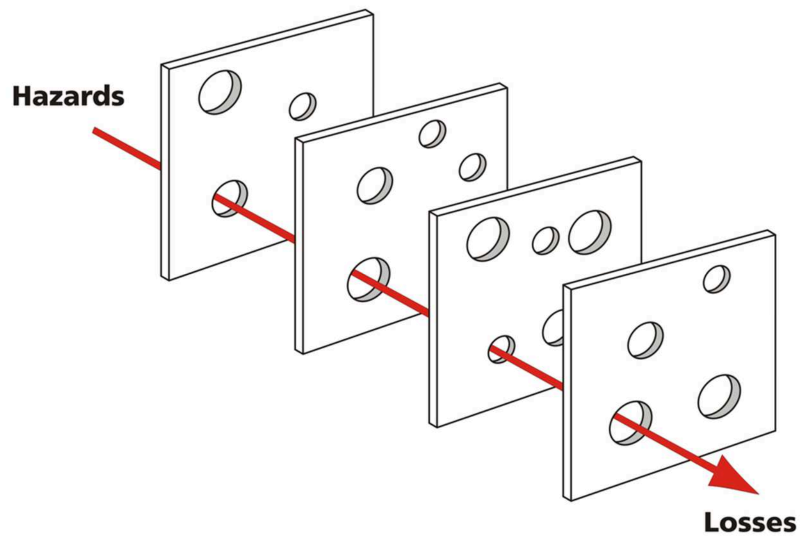

Figure 4-1. Swiss cheese model of accident causation
Source: Reason, (2000)

Decision making is the cognitive process that results in a choice between two or more alternatives. Robbins and Judge (2007) outline six steps for such a process: (1) define the problem; (2) identify decision criteria; (3) weigh the criteria; (4) develop alternatives; (5) evaluate the alternatives; and (6) choose the best alternative. They also highlight that influences on a decision include both internal factors (e.g., decision-maker's knowledge, values, experiences, motives, and expectations) and external factors (e.g., time, work setting, social situation, and proximity). A decision-making chain is an ordered series of decision-making processes within a specific context. Biases and errors may occur when a decision-maker's perception and reality are discrepant, often representing a tendency to overestimate internal influences and/or underestimate external influences. As a result, the decision-making study emphasizes on the identification of alternatives and the context of influences; while, in addition, the study of decision-making chain also highlights the organization of the decision-making series.

The context of influences on decisions may change by occupation, task, or situation. This uncertainty is especially important to the construction industry. Different from manufacturing, the construction industry is characterized by a "one-off" nature that means each construction project is unique and the nature of the industry is fragmented. Applicable solutions are consequently only specific to projects and/or tasks of specific projects (Blayse & Manley, 2004). In turn, this nature highlights the importance to identify the context of influences for a decision-making chain because there is no universally applicable context in construction. In other words, the decision-making chain only when embed in a specific context within a project can reveal useful information for understanding activities and sequences that lead to OSH injuries.

In construction quality control (QC), the context of influences are termed a "feature of work" (FOW). The U.S. Army Corps of Engineers (COE) describes an FOW as a kind of task that is separate and distinct from other tasks in terms of control requirements and unique work crews. A FOW can also be seen as a phase of work requiring a separate preparatory inspection. Integrating the FOW concept into OSH research, the authors would like to define it as a group of distinctive activities that possess higher OSH risks and require particular attention. In view of the project nature or OSH purpose an FOW can be represented in terms of building elements (e.g., erection of steel columns), work breakdown packages (e.g., pipe works, roof framing, HVAC), or project schedule (e.g., erecting first floor steel framing). All FOWs need to be defined narrowly enough to ensure adequate identification of OSH hazards.

Meanwhile, distinctive OSH injury circumstances allow for decision-making study while providing a possibility for FOW identification. In an accident, a series of decisions are influenced by various contributing factors so that a critical decision point within the series can be traced back in an earlier phase prior to the injury occurrence (Behm, 2005). In other words, contributing factors can be used to interpret fatality and thus be able to identify an FOW. Features of work can be studied by classifying homogeneous construction activities or workplace circumstances and using a decision tree model, a widespread graphical technique to determine decisions and their possible consequence (see Figure 4-2).

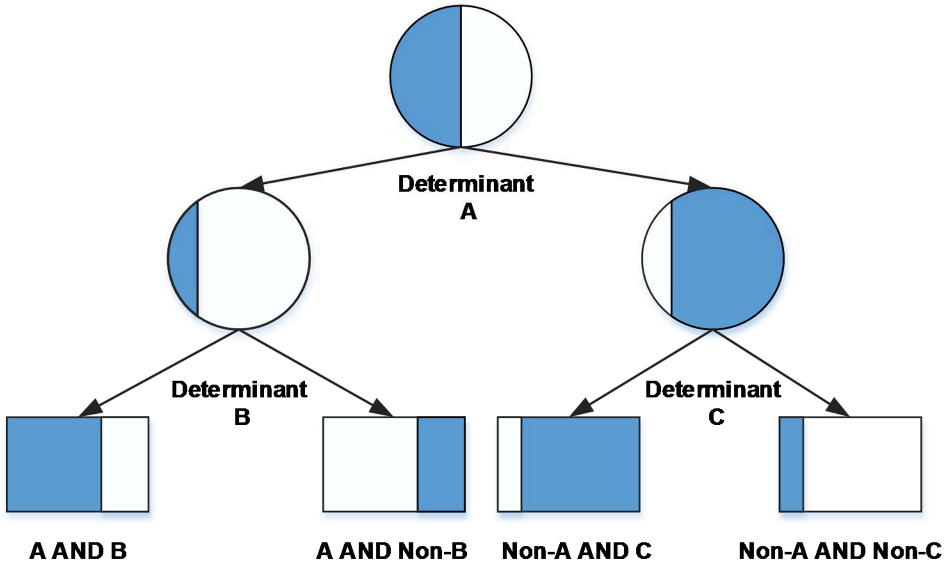

Figure 4-2. Decision-tree classification model

Various decision tree models exist and contain differing algorithms. The prevailing ones include automatic interaction detection (AID); chi-squared automatic interaction detection (CHAID); classification and regression trees (CART); quick, unbiased, efficient statistical tree (QUEST); and C5.0/C4.5 (Tufféry, 2011). AID was first developed by Sonquist and Morgan (1964) to seek sequential partitioning of the observation matrix to identify critical determinants and segregate subgroups individually (Hawkins & Kass, 1982). Mathematically, AID is an extension of one-way ANOVA under predetermined bounds and constraints by splitting the data successively into many binary subgroups and achieving the minimum residual sum of squares. Evolving from AID, CHAID allows researchers to analyze the inter-correlation of categorical variables through reducing the problem size while AID only allows analysis on continuous variables (Hasan & Jha, 2012). CART was developed by Breiman et al. (1984) to seek the best split by recursively splitting the observations at each node. All candidate variables are screened and whichever variable yields a split which maximally improves classification is chosen, until the maximum homogeneity criterion is reached (Witten & Frank, 2005). CART requires a set of historical data as the learning sample to build the splitting rules for classifying new observations. QUEST was developed by Loh and Shih (1997) which resembles the CART algorithm to minimize bias in variable selection. This change allows to generate more compact classification trees with unbiased and highly accurate splits (Lim et al., 2000). C4.5 and its later version C5.0 were computer programs developed by Quinlan (1993) with featured boosting technology to increase accuracy. The splitting criterion of C5.0 is to seek the maximum normalized information gain rather than entropy to find out the lowest-level splits (Tan, 2006). C5.0 requires a learning sample to grow or “prune” the decision tree as well.

Few studies have addressed electrical hazards for construction workers through the lens of decision-making chain, though. To fill this gap, this work attempts to identify electrical-hazard-related features of work and then analyze OSH decision making in each feature of work for construction workers. With such a goal, the research proposes to utilize decision-making diagrams as final results to present critical decision points, decision logic, and decision constraints. Specifically, outcomes of the study are expected to answer three questions, as follows:

a) What features of work may lead to electrical injury or fatality?
b) How is the decision-making chain organized in each feature of work?
c) What critical constraints influence the decision-making chain?

By answering these questions, findings will contribute to hazards present in the decision-making chain and its analysis in construction safety research and ultimately to the prevention of electrical injuries for industry. Also, the comprehensive approach demonstrated in this study is applicable to other OSH research such as accident analysis and prevention.

4.2 DATA AND FACTORS

Decisions are made at different point of time, which raises the necessity of building the link between predictors and the sequence. Haddon’s matrix provides a flexible theoretical framework for establishing the link and coding information about a spectrum of contributory factors (Bondy et al., 2005). Haddon’s matrix (Haddon, 1972) has four columns and three rows, where rows represent three accident sequence phases (pre-event, event, and post-event) and columns represent four aspect categories (host, vector, physical environment, and social environment). Pineault, Rossignol, and Barr (1994) ascertained that this matrix was an appropriate systematic tool in describing occupational electrocutions in all their aspects or in an orderly time sequence.

Coded surveillance injury data are useful for identifying common causes of death and worker groups, however they may not be capable of providing sufficient in-depth information to understand circumstances and contributors to fatal injuries (Bunn et al., 2008; Higgins et al., 2001). In contrast, narratives of accident investigations contain such information including the initiating actions, worker demographics, workplace environment, pre-event activities, activities during the fatal event, and post-event activities (Bunn et al., 2008), which are supplemental information on additional unknown risk predictors for decision-making analysis (Lincoln et al., 2004).

Existing studies show that the Fatality Assessment and Control Evaluation (FACE) investigations from the National Institute of Occupational Safety and Health (NIOSH) are an eligible data source satisfying the needs of this construction safety research (Bunn et al., 2008; Higgins et al., 2001; Zhao, Thabet, et al., 2014). FACE investigations are comprehensive, narrative-based injury fatality reports, including detailed information on behavioral, environmental, and organizational predictors, according to Haddon's method, similar to the host (victim workers), vector (e.g., tools), and the physical and social environments of the workplace across the pre-event, event, and post-event phases. Based on these merits, this work uses FACE investigations as they provide adequate circumstances covering the entire accident period. This research therefore extracted 144 FACE investigations from NIOSH's website, which constitute all available electrocution cases ranging from 1989 to 2012.

Zhao, Thabet, et al. (2014) conducted a descriptive analysis of FACE investigations and revealed the typical features of electrical fatalities in construction, distilling them into a series of factors. Based on that research, this study adopted 19 factors to explain the influences on decision-making. The final set of 19 factors (see Table 4-1) are listed in a form of Haddon's matrix which Pineault et al. (1994) created for interpreting the time sequence of electrocution. Specifically, new factors are: PPE (personal protective equipment), task, crew, death time, EMS (emergency medical services), and CPR (cardiopulmonary resuscitation). All factors are also considered predictors in the decision-tree classification analysis.

Table 4-1. Summary of factors/predictors.

	Pre-event Phase (before shock)	**Event Phase (electric shock)**	**Post-event Phase (after shock)**	**Description**
Host	**Age**: how old. **Gender**: male/female. **Occupation**: profession.	**Contact:** direct or indirect.	**Death time**: when the victim was declared dead.	Victim's demographic or other information.
Vector	**Vehicle**: tools, machines, equipment that the victim use. **PPE**: qualifiedly wore or not.	**Task**: the work activity the victim was doing. **Agent**: an object that the victim was touching.	Not applicable	Vehicle, equipment, and construction material that directly related to victim's task.
Physical Environment	**Time**: when the accident occurred. **Workplace**: where the accident occurred.	**Voltage**: what volt. **Source**: the origin of electricity	Not applicable	Whereabouts, environmental factors, equipment, vehicles or material present but not related to victim's task.
Socio-professional Environment	**Project type**: the construction type. **Written policy**: provided or not. **Safety training**: provided or not.	**Crew**: with co-worker or alone.	**EMS**: provided or not. **CPR**: provided or not.	Employer's policies, laws and regulations, pre-hospital medical services.

4.3 METHODS

4.3.1 Overview

As stated in the introduction section, the goal of this work is to incorporate three primary research aims:

a) identify the features of work (FOW)
b) map out the organization of decision-making chain for each FOW; and
c) identify constraints for the decision-making chain.

To achieve the goal, this study was designed consisting of four main stages:

a) review fatality investigations and extract useful information;
b) code the information in a categorical format, using the designated factor framework previously shown in Table 4-1;
c) identify the features of work, using a decision tree model (Exhaustive CHAID); and
d) develop a decision-making chain for each identified features of work, using function modeling diagram (IDEF-0 method).

It is important to note that a panel of safety experts reviewed the coding process for reliability. The panel consisted of university faculty and OSHA safety professionals (some of whom are from the FACE program). These experts have more than ten years of experiences in the teaching, research, or administration of construction safety. Given this study, the mission of the safety expert panel was to provide consulting advice to the research. The panel also advised the research on correct coding and understanding investigation reports for accident factors, helping to ensure validity for this portion of the work.

For analysis, this study used Exhaustive CHAID as the specific decision-tree technique. The goal of the Exhaustive CHAID analysis was to classify homogenous electrocution scenarios and then, based on scenarios, identify the FOW. Human mistakes can lead to poor decisions and are considered as a major reason for most OSH incidents (Zhao, McCoy, et al., 2014). They often appear when a worker has no rules to apply to a situation or applies one incorrectly (Manseau & Shields, 2005). As a result, this research used the mistake event, which contributes to the occurrence of electrocution, as the dependent predictor in the analysis. 12 typical decision-making mistakes are concluded from fatality investigations by the researcher and confirmed by the safety expert panel, as listed in Table 4-2. As a result, scenarios are classified depending on the relationship between decision-making mistakes and the aforementioned 19 factors (or predictors).

Table 4-2. Decision-making mistakes

ID	Decision-making mistakes	Phases
DM-01	Lack of basic electrical safety knowledge	Pre-event
DM-02	Improper use of PPE or electricity testing equipment	Event
DM-03	Lack or failure of site surveying	Pre-event
DM-04	Violation or action without permission	Event
DM-05	Failure of insulation by de-energizing or grounding	Pre-event event
DM-06	Design flaw of safety procedures or preventions	Pre-event
DM-07	Failure of guarding worker, warning sign, or safety supervision	Pre-event, event
DM-08	Failure of lockout/tagout	Event
DM-09	Damaged tools, wires, or equipment.	Pre-event, event
DM-10	Failure of maintaining safe distance	Pre-event, event
DM-11	Improper use of tools and machinery	Event
DM-12	Poor safety climate (pressure, fatigue)	Pre-event, event

This work also used the IDEF-0 method as the function modeling technique to interpret the decision-making chain in electrical safety for construction workers. Despite the visualization function, IDEF-0 is rich in illustrating information for better understanding influences on decisions, resources, and decision alternatives that affect each key decision. Particularly, the researcher used IDEF-0 to map the general sequence of decision-making series in a feature of work, and capture the key decision controls and mechanisms influencing the decision-making. The controls and mechanisms are categorized into a predefined schema which was developed based on previous work from Kleiner (1997) and approved by the safety expert panel. Of this schema, the 6 control categories are:

- C1: OSH Knowledge (awareness or experience of OSH)
- C2: Policies (OSH regulations, procedure standards, or requirements)
- C3: Efficiency (adequate qualified resources)
- C4: Productivity (quality of being productive)
- C5: Collaboration (communication or coordination with third parties)
- C6: Funding (budget and cost)

And the 5 mechanism categories are:

- M1: Professionalism (skills or good judgment of specific occupation)
- M2: Equipment (hand tools, or machinery)
- M3: Materials (construction or OSH materials)
- M4: Time (schedule)
- M5: Space (physical environment)

4.3.2 Exhaustive CHAID

The Exhaustive CHAID algorithm which was created by Biggs et al. (1991) is an improved version of the basic CHAID. Both of them are used to test the relationship of a dependent variable and a series of predictor variables (also termed predictors), resulting in a decision-tree starting from the root node through the merging, splitting, and stopping steps. The Exhaustive CHAID algorithm has the same steps of splitting and stopping with CHAID while has different step of merging. CHAID cycle through the predictors to determine for each predictor the pair of categories that is least significantly different (i.e., most similar) with respect to the dependent variable; while Exhaustive CHAID performs a more thorough merging and testing of predictors by continuing to merge any similar pair of categories until only two categories remain for each predictor.

Mathematically, CHAID (or Exhaustive CHAID) classification relies on the Chi-squared test of association. When the dependent variable is nominal, the Person's Chi-squared statistic (see equation 1) and its related *p*-value are computed. If the corresponding *p*-value is not statistically significant, the algorithm merges the perspective predictor categories; otherwise it splits the predictor into branches. This computation is repeated until the final tree (best splits) is grown.

$$\chi^2 = \sum_{j=1}^{J} \sum_{i=1}^{I} \frac{(n_{ij} - \hat{m}_{ij})^2}{\hat{m}_{ij}} \qquad \text{(Equation 4-1)}$$

where n_{ij} is the observed cell frequency while $\hat{m}_{ij}$ is the estimated expected cell frequency for cell ($x_n = i$, $y_n = j$) in the contingency table.

Exhaustive CHAID is appropriate for satisfying the current research objectives and that is the reason it was chosen for the decision-tree classification analysis. The researcher compared the five popular decision tree models and summarized their different features, as listed in Table 4-3. As a result, CHAID (same as Exhaustive CHAID) satisfies the goals of the current research based on the following:

- Split Type (N-ary split): CHAID allows the optimal multiple-split of each node. In contrast, CART or QUEST can only yield binary trees, which sometimes cannot be efficiently summarized for interpretation and presentation (Gilbert, 2010; Tufféry, 2011).
- Variable type (N/O/I): most variables in this research are nominal and CHAID has the advantage on analyzing nominal data (T. Hill & Lewicki, 2006).
- Accuracy (High): CHAID has higher performing accuracy at 83.82% (Chou, 2012), compared to other similar models like QUEST and C5.0.
- OSH adoption (Yes): CHAID has been widely adopted in OSH research (Chi, Chang, & Hung, 2004; Hartling et al., 2002), being believed to be a capable method for this work.

Table 4-3. Comparison of popular decision tree techniques.

Aspects	**AID**	**CHAID**	**CART**	**QUEST**	**C5.0**
Split type	Binary	N-ary	Binary	Binary	N-ary
Splits per node	2	≥2	2	2	≥2
Variable type*	O/I	N/O/I	N/O/I	N/O/I	N/O/I
Regression-type	Yes	Yes	Yes	No	No
Interaction detection	Yes	Yes	No	No	No
Adoption in OSH	Yes	Yes	Yes	No	No
Accuracy	Normal	High	Normal	High	Normal
Misclassification costs	No	No	Yes	Yes	No

*: N = nominal; O = ordinal; I = interval.

4.3.3 IDEF-0 method

The IDEF-0 (Integration Definition for Function Modeling, type 0) is a function modeling method, also a process mapping tool, used to graphically represent the decisions, actions, and activities of a system (Grover & Kettinger, 2000). The application of IDEF-0 leads to a flow diagram that comprises a series of boxes linked with arrows. As shown in Figure 4-3, the basic components of an IDEF-0 diagram are the function box (representing a decision-making process) and the arrows (representing movements with direction). The relationship between a function box and an arrow determines the role of the arrow, including:

- Inputs: decisions or actions that are transformed to the function to produce outputs, entering the left side of a box;
- Outputs: decisions or actions that are produced by the function, exiting a box from the right side;
- Controls: conditions that constrain the decision-making process, entering a box on the top;
- Mechanisms: the resources for making a decision, entering a box from the bottom.

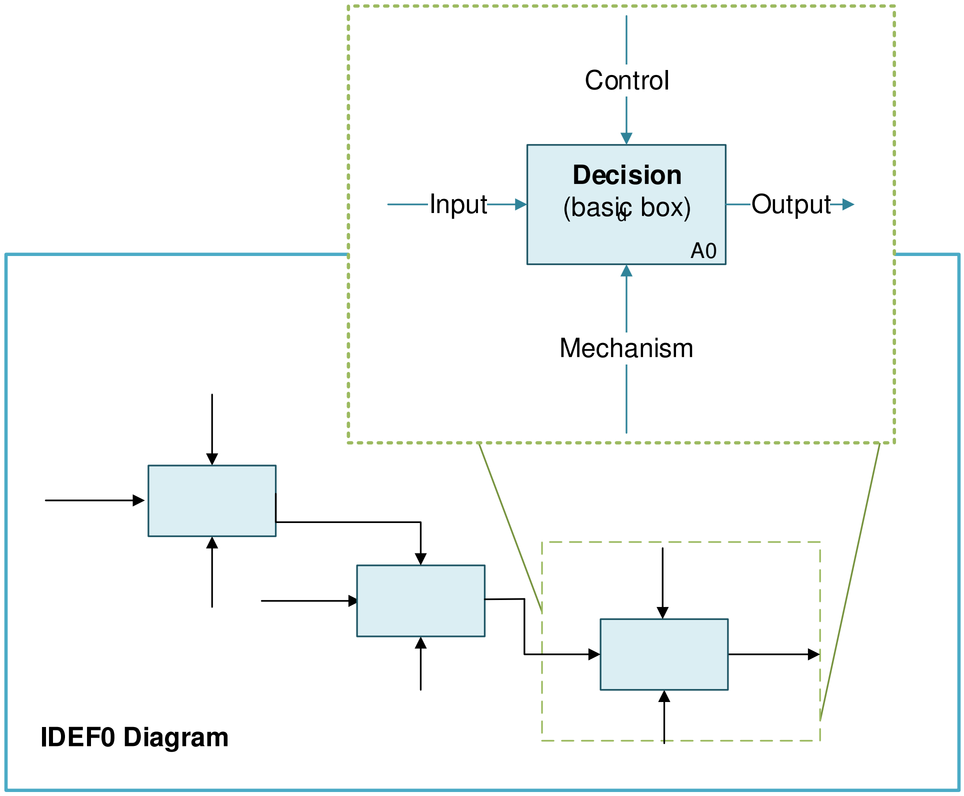

Figure 4-3. IDEF-0 decision process mapping structure.

The IDEF-0 method has two primary strengths for this research. The first strength is the flexibility in detailing the decision-making chain that are described by their related inputs, outputs, controls, and mechanisms. Such description can be easily refined into greater detail until the diagram is sufficient for describing a decision-making chain. The other strength is its capability of representing the sequence of decision-making series. Often, a series of decision-making processes (the function boxes) are placed in a left to right fashion connected with input/output arrows, which are able to clearly demonstrate the sequencing.

The IDEF-0's is also capable of decomposing a decision-making process (a function box) into its component decision-making steps (as previously stated in the introduction section) with a child IDEF-0 diagram (Leonard, 1999). Based on the research objectives, this study does not go that far to analyze decision-making steps. As a result, the IDEF-0 diagrams resulting from this study do not include child diagrams that exhibiting information of decision-making steps, unless otherwise noted.

4.4 RESULTS

4.4.1 Features of work

Computed using SPSS software, Figure 4-4 is the classification tree resulting from the Exhaustive CHAID analysis. The tree, representing the "best splitting" across 19 predictors (as previously listed in Table 4-1), consists of a root node (node 0), six leaf nodes (node 1-6), and distinctive branches connecting the nodes. These leaf nodes are mutually exclusive and exhaustive, and can be used to determine the features of work associated with electrical hazards. When looking at the tree structure, it seems that the predictor "task" is the closest to the root and splits the total population into four nodes (node 1, 2, 3, 4). This organization means that the "task" is the most critical factor ($\chi^2 = 123.552$, $p < 0.001$), and suggests that the decision-making mistake is significantly (at 99% confidence level) related the "task" (i.e., the construction work that the worker is performing). Similarly, at a lower level of the tree under the node split by predictor "task", another significant predictor is identified: the "agent" ($\chi^2 = 29.303$, $p = 0.012$), which splits node 4 into two leaves (node 5 and 6). Interesting to the author, the findings from the Exhaustive CHAID analysis imply that the decision-making mistake is significantly related to the Technique (reflected by predictor "task") and Physical environment (by predictor "agent") while comparatively less important to the Host or Social environment.

Based on the merged categories in the five end nodes (node 1, 2, 4, 5, 6) from the decision tree, the researcher identified five features of work and interpreted them in Table 4-4. These FOW are: 1) the Construction of utility systems, 2) Equipment positioning, 3) Construction of electrical systems, 4) Construction of building enclosures, and 5) Materials transportation. Among the five, only two features of work (namely FOW-1 and FOW-3) are associated to electrical tasks while the other three (FOW-2, FOW-4, and FOW-5) are related to non-electrical activities.

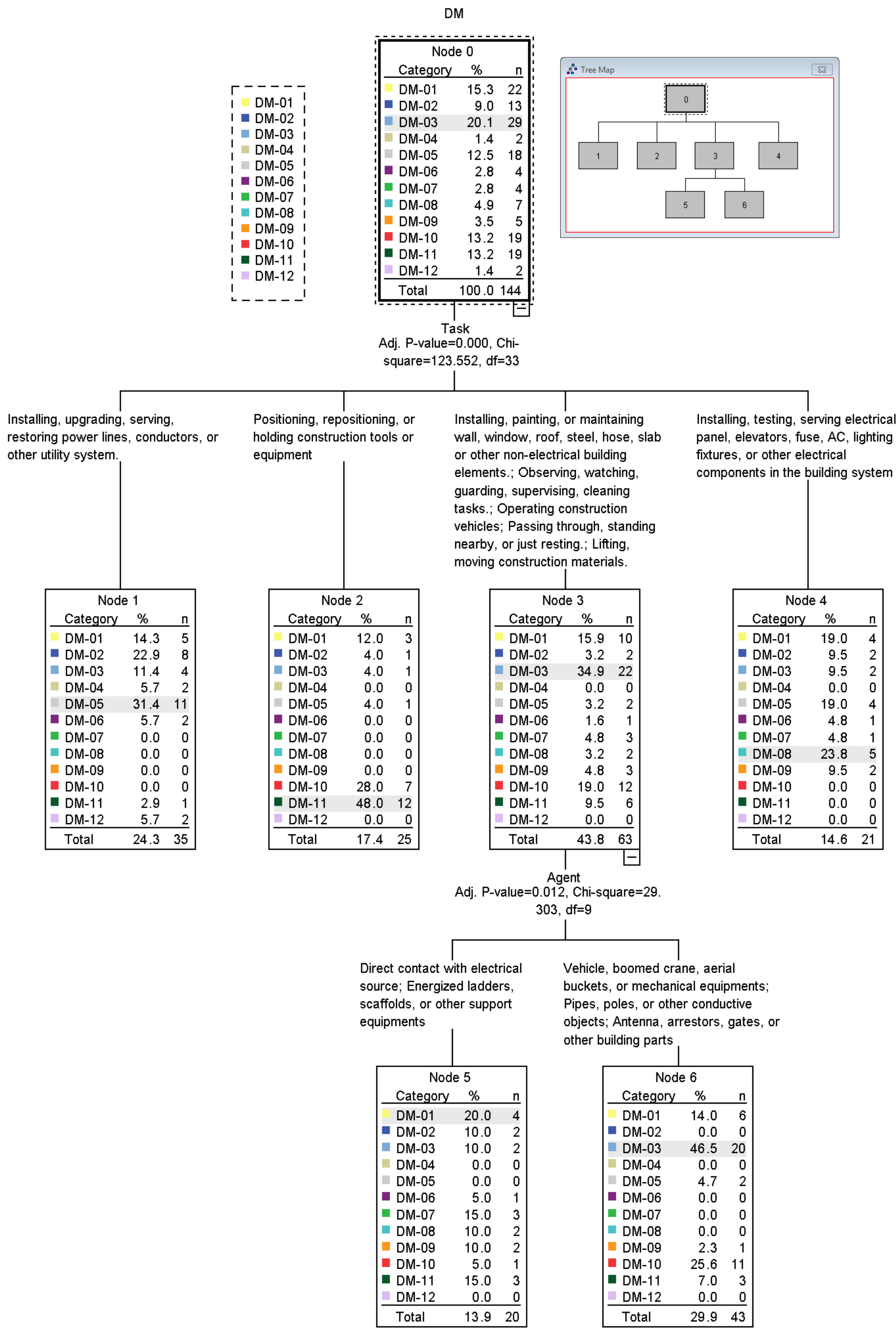

Figure 4-4. Classification tree resulting from Exhaustive CHAID.

Table 4-4. Summary of identified features of work.

ID	Node	Feature of work	Description
FOW-1	1	Construction of utility systems	Installing, upgrading, serving, restoring power lines, transformers, or other utility system.
FOW-2	2	Equipment positioning	Positioning, repositioning, or holding construction tools or equipment, e.g., ladders, crane rigs, scaffolds, platform, or aerial lifts.
FOW-3	4	Construction of electrical systems	Installing, testing, serving electrical panel, elevators, fuse, AC, lighting fixtures, or other electrical components in a building system.
FOW-4	5	Construction of building enclosures	Installing, painting, or maintaining wall, window, roof, steel tower, antenna, hose, or other non-electrical building elements.
FOW-5	6	Materials transportation	Lifting, moving construction materials, e.g., pipe, drill, pole, steel, slabs, either through manpower or operating construction vehicles, e.g., crane, truck.

Findings suggest that for FOW-1(Construction of utility system), the heavy and civil engineering construction contractors (57%) and relevant specialty trade subcontractors (40%) are the major employers. Most of these firms have written safety policies (74%) and/or provide their employees safety training (63%). Line installers and repairers (77%) are the dominant occupation involved. The worksites include utility pole, substation, transformer site, power plant, and residence, of which the utility pole takes the largest portion at 69%. 83 % of involved voltage is of medium voltage (1,000 to 16,000 volts), implying that the electricity source comes from the distribution power lines between the substation and end customers. FOW-1 contains high risk of failure of insulation (de-energizing or grounding electric source). More than half of the fatalities (57%) involved in this FOW were declared as dead on arrival (DOA) or dead at the scene (DATS), indicating high severity of injuries.

For FOW-2 (Equipment positioning), building construction contractors (44%) and relevant specialty trade subcontractors (36%) are the major employers. A minority of these firms have written safety policies (40%) and/or provide their employees safety training (32%).

Construction laborers (24%) and painters (24%) are the primary occupations involved. Related equipment includes aluminum ladders, rolling scaffolds, tower scaffolds, forklift platforms, aerial lifts, and aerial buckets. The worksites include apartment, condominiums, houses, schools, stores, warehouses, factories, and roads, of which residential buildings constitute the largest portion at 44%. Similar to FOW-1, the voltage (68%, ranging from 1,000 to 16,000 volts) suggests an electricity source from distribution power lines between the substation and end customers. FOW-2 is highly related to the improper use of tools and machinery. More than two thirds of fatalities (68%) involved in this feature of work were declared as DOA or DATS, indicating high severity.

For FOW-3 (Construction of electrical system), specialty trade constructors (86%) are the primary employers throughout projects in residential, commercial, industrial and heavy construction. Approximately half of these firms have written safety policies (57%) and/or provide safety training (48%). Electricians (71%) dominate this feature of work. The worksites include apartments, houses, stores, offices, shopping malls, factories, recreational facilities, restaurants, airports, light poles, or substations, 67% of which are indoors. 73% of the involved voltage is 480 volts or below, implying that the electrical hazards for FOW-3 are at residences or business buildings. FOW-3 is highly related to the failure of lockout/tagout. Almost half of fatalities (48%) involved in this feature of work were declared as DOA or DATS, indicating medium-to-high severity.

For FOW-4 (Construction of building enclosure), employers are almost equally distributed throughout the whole construction sector. Similar to FOW-2, a minority of these firms have written safety policies (23%) and/or provide their employees safety training (32%). A variety of occupations may be involved such as construction laborers, roofers, finishers, pipe layers, plumbers, painters, and carpenters. The worksites include condominiums, houses, warehouses, offices, factories, industrial plants, and bridges, 55% of which are in the vicinity of residence. Both medium voltage (1,000-1,600 volts) and low voltage (below 1,000 volts) constitute large portions in this feature of work, accounting for 50% and 32%, respectively. Injuries in FOW-4 suggest a lack of basic electrical safety knowledge. More than half of fatalities (55%) involved in this feature of work were declared as DOA or DATS, indicating high severity.

For FOW-5 (Materials transportation), specialty trade contractors, especially in residential and heavy construction projects such as Building Equipment Contractors, are the primary employers. A minority of these firms have written safety policies (31%) and/or provide their employees safety training (31%). Construction equipment operators (41%) and construction laborers (31%) are the primary occupations involved in this FOW. The worksites include houses, schools, roads, substations, churches, office buildings, roads, utility poles, traffic signs, and sewer infrastructure, 93% of which are outdoors. 79% of the involved voltage is of medium voltage (1,000 to 16,000 volts), implying that the electricity source is from distribution power lines between the substation and end customers. FOW-5 is highly correlated to failures of worksite surveying. More than half of fatalities (57%) involved in this feature of work were declared as DOA or DATS, indicating high severity.

4.4.2 Decision-making chains

Our data show that most victims lose consciousness after being shocked, unable to make rational decisions. The data also show that all victims received emergency medical services (EMS), implying less significance for the post-event phase. Moreover, the goal of this work is to find out critical decision points prior to the injury occurrence, which may contribute to more effective accident interventions. In view of these concerns, the decision-making chain only maps decision-making - processes during pre-event and event phases.

FOW-1 Construction of utility system

Figure 4-5 illustrates the decision-making chain for FOW-1, including four critical decision points: FOW-1-1 (“onsite hazard survey”), FOW-1-2 (“de-energize power lines”), FOW-1-3 (“choose PPE”), and FOW-1-4 (“work on utility”). Among the four points, the latter three may directly lead to safe performance if one is making a correct decision. FOW-1-2 has the least number of decision influences (two controls, namely collaborating and utilizing proper PPE), which seem to be the most effective point to eliminate electrical hazards. FOW-1-3 is largely influenced by PPE’s efficiency. FOW-1-4 has the most number of influences (5 controls) and becomes the most difficult point to make correct decisions or take appropriate action. FOW-1-1 is also important being the only path to reach FOW-1-2, though it cannot immediately mitigate a risk.

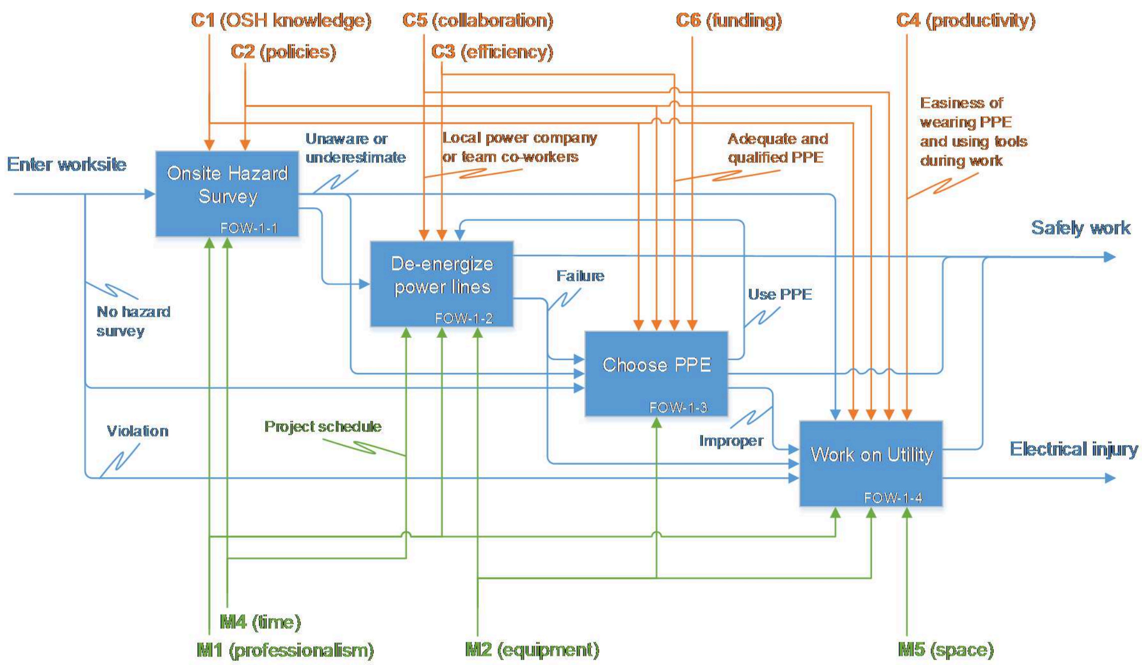

Figure 4-5. Decision-making chain in the construction of utility system.

The diagram suggests two interesting findings. First, an earlier decision for prevention receives less negative influences, in terms of time sequencing. Thus, "de-energizing power lines" (FOW-1-2) appears to be the most effective way to eliminate an electrical hazard. Nevertheless many fatalities in utility construction were due to this failure. For example, many investigations indicated linemen who thought live power lines had been de-energized and then removed their gloves and sleeves during work on a utility system. Second, the design and usage of PPE or energy-cutting tools may be a weakness. For example, many cases involved the ease of use and effectiveness of hot stick, rubber gloves, sleeves, jumper, bayonet fuses, fall harnesses, hoists, or hocks. Therefore, insufficient collaboration and technology are the two significant constraints on FOW-1's decisions.

FOW-2 Equipment positioning

Figure 4-6 illustrates the decision-making chain for FOW-2, indicating four critical decision points: FOW-2-1 ("onsite hazard survey"), FOW-2-2 ("de-energize power lines"), FOW-2-3 ("choose equipment"), and FOW-2-4 ("position equipment"). Among the four, the latter three points may directly lead to safe performance if making a correct decision. Similar to FOW-1-2, FOW-2-2 is the earliest and most effective decision point for prevention (also only via FOW-2-1); however, workers' professions contradict this decision because of their non-electrical occupations. FOW-2-3 is largely influenced by equipment efficiency and budget; for example, a fiberglass ladder is considered trade specific for electricians and often more expensive than an aluminum one. FOW-2-4 is the most difficult point due to a variety of influences.

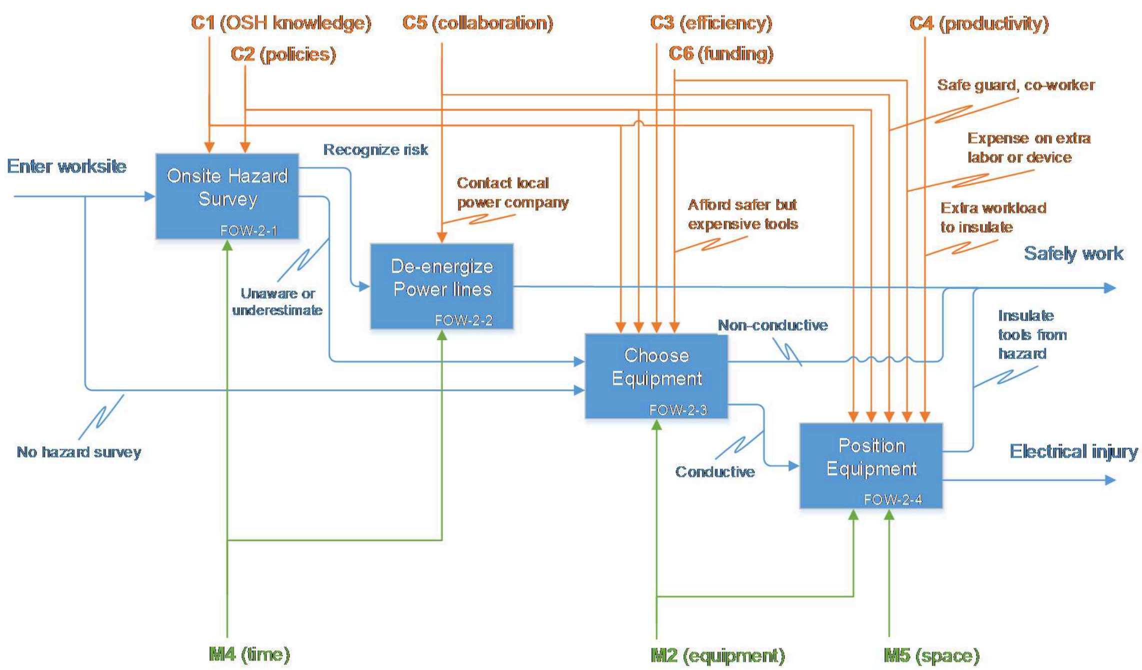

Figure 4-6. Decision-making chain in the equipment positioning.

Note that neither asking a local power company to shut down distribution lines nor cutting off lines by the worker him or herself helps much amenable for this feature of work, especially in densely populated areas. Therefore, choosing non-conductive and stable supporting equipment and/or setting reasonable distance before positioning them, seems more practical. As a result, the lack of appropriate equipment and inadequate funding are significant constraints on FOW-2's decisions.

FOW-3 Construction of electrical system

Figure 4-7 illustrates the decision-making chain for FOW-3, indicating four critical decision points: FOW-3-1 ("onsite hazard survey"), FOW-3-2 ("disconnect"), FOW-3-3 ("choose PPE"), and FOW-3-4 ("electrical work"). Among the four, the latter three points may directly lead to safe performance if making a correct decision. FOW-3-1 is not the only path to effective prevention action but remains important for not missing any electrical sources. FOW-3-2 is an essential decision point that is influenced by policies, efficiency and collaboration. FOW-3-3 is largely influenced by PPE's productivity and worker's OSH knowledge. Similarly, FOW-3-4 is the last and most difficult point to take appropriate action.

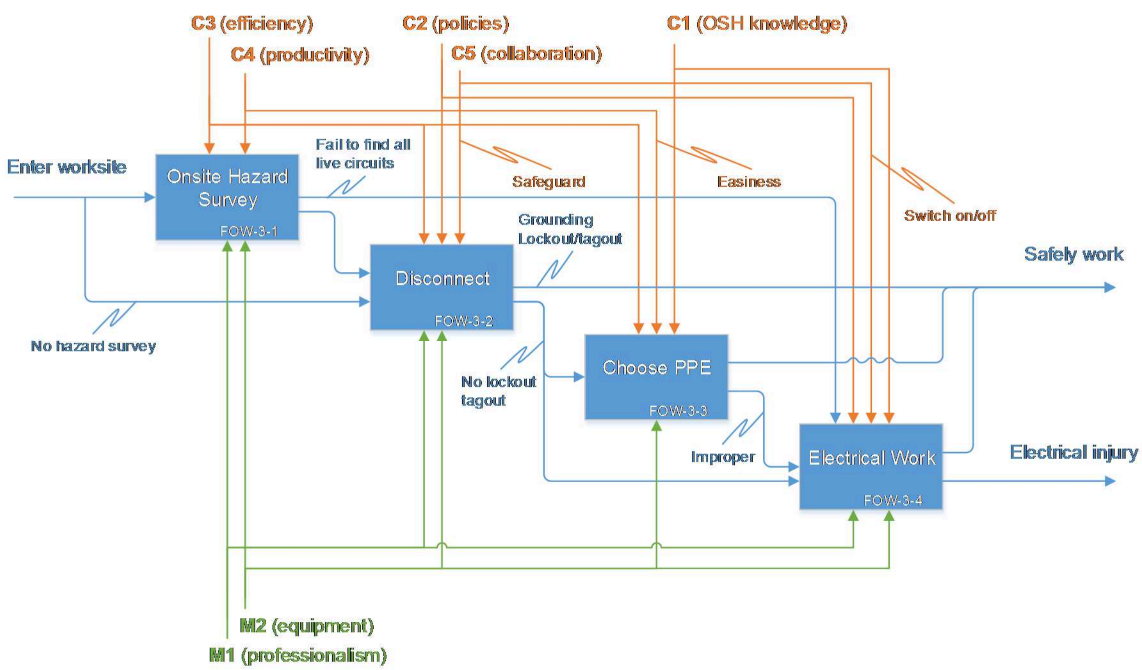

Figure 4-7. Decision-making map in the construction of electrical system.

Three observations from this diagram are noteworthy. First, starting by disconnecting electricity is embedded in every electrician's nature. Second, current technology is fully capable of providing reliable and economic PPE for low-voltage protection. Third, a thorough onsite hazard assessment remains indispensable, even for an experienced electrician. Based on one case, a fatality occurred when an electrician was electrocuted due to a lack of awareness of temporary circuits during an elevator installation. Combining all observations indicates an interesting finding that workers' electrical knowledge or regulation compliance could be part of the problem. For example, many investigation cases show that electricians did not used or removed a safety switch, GFIC, grounding wires, or fuses, or did not properly wear PPE in the workplace. Therefore, insufficient professional and policy enforcement are significant constraints on FOW-3's decisions..

FOW-4 Construction of building enclosure

Figure 4-8 illustrates the decision-making chain for FOW-4, indicating three critical decision points: FOW-4-1 ("onsite hazard survey"), FOW-4-2 ("insulate"), and FOW-4-3 ("work on roof and facade"). FOW-4-1 may lead to hazard awareness while FOW-4-2 and FOW-4-3 may lead to injury intervention and result in safe performance. All the three decisions are largely influenced by workers' OSH knowledge.

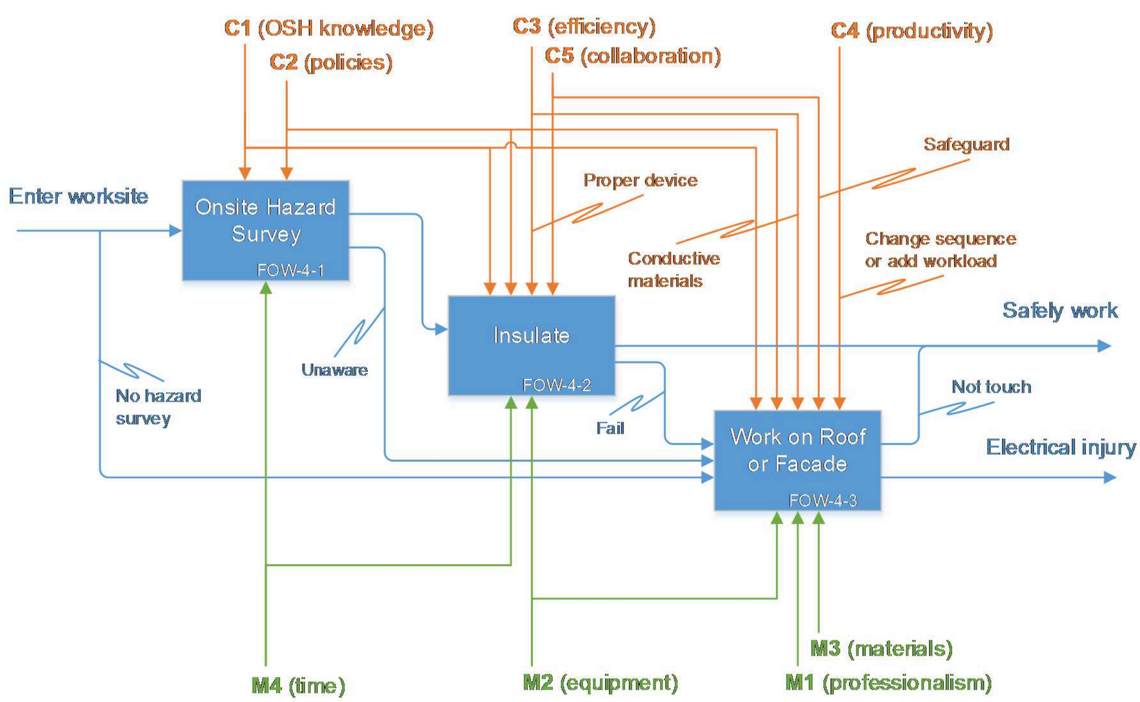

Figure 4-8. Decision-making chain in the construction of building enclosure.

Figure 4-8 suggests that enclosure-construction workers are short of basic OSH knowledge on electrical hazards. Insufficient safety training on hazard awareness and/or insulation may put them in situations surrounded by electrical hazards and beyond their professional knowledge and expertise. As a result, they become more reliant on information and guidance from safety professionals, such as safety manager or superintendent. Therefore, insufficient OSH knowledge and collaboration are significant constraints on FOW-4's decisions.

FOW-5 Materials transportation

Figure 4-9 illustrates the decision-making chain for FOW-5, indicating four critical decision points: FOW-5-1 ("onsite hazard survey"), FOW-5-2 ("set distance"), FOW-5-3 ("operate machine"), and FOW-5-4 ("move materials"). Among the four, only FOW-5-2 and FOW-5-4 provide intervention while the former contain few, effectively leading to safe performance. In contrast, both FOW-5-3 and FOW-5-4 can directly cause electrical injuries.

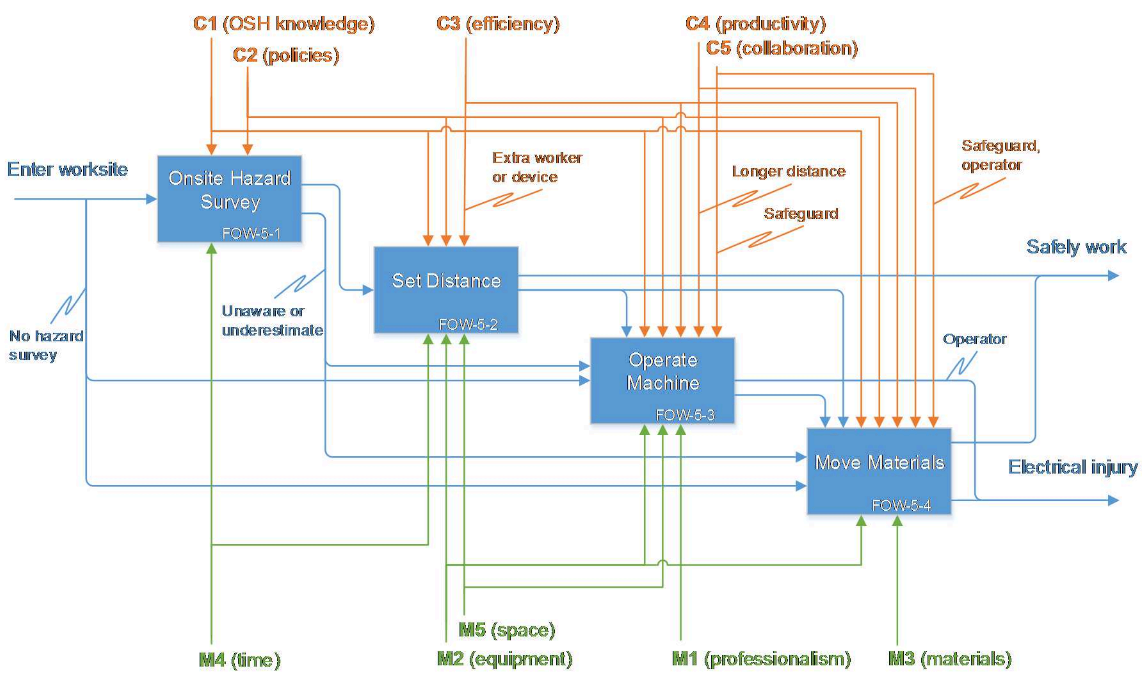

Figure 4-9. Decision-making chain in the materials transportation.

Figure 4-9 suggests three interesting findings. First, overhead power lines, as the related hazard, are not difficult to identify if conducting a thorough site survey. Second, the corresponding invention measure is to insulate electricity source by keeping at a distance of at least 10 feet and requiring good communication with safeguard, watcher, or supervisor. Third, workers who are moving materials, especially vertically, engage in high risk from inappropriate decisions either by themselves or machine operators. Coupling all above, it seems that insufficient OSH knowledge, police enforcement, and collaboration are significant constraints on FOW-5's decisions.

4.5 DISCUSSION

The goal of this study is to elaborate the critical points and constraints in the decision-making chains pertaining to electrical safety, and ultimately to improve construction workers' safety and promote hazard mitigation in OSH. As a result, findings may be contribute to developing safe procedures for the identified features of work, and may also contribute to injury control by recommending interventions at a certain decision point.

Of interest, a homogeneity of decision-making existing across all the features of work is worth special attention: an earlier intervention decision mitigates better and has a greater impact. The finding confirms a current prevention strategy: prevention through design (PtD). The mission of PtD is to eliminate hazards and control risks for workers at an acceptable level as early as possible in the workplace. The time/safety influence curve implies that hazard mitigation at an earlier process stage can have a greater impact, because hazards can possibly be eliminated or controlled more effectively than using PPE (Behm, 2005). From the perspective of hierarchy of controls (HOC), risks also need to be designed out of features of work, which is better than being mitigated through administrative interventions or PPE at a lower level of HOC (Zhao, Thabet, et al., 2014).

Further, many of the identified decision constraints are outside of the scope of construction work itself, which indicates a need for innovative and progressive process from all stakeholders in the architecture, engineering, and construction (AEC) industry. However, in the United States, OSH safety is primarily considered the domain of the constructor in order to avoid the liability associated with dictating "means and methods". Typical contract terms clearly state that designers are not responsible for the safety of construction workers. To the contrary, PtD strategy focus on workers' safety but more likely require emphasis on a design's intent.

In conclusion, reliable and effective prevention strategies advocate the implementation of "designing safety in" and "designing hazards out". The reliance on design to eliminate or avoid hazards prior to exposure in the workplace is also listed as a top priority in OHSA's hierarchy of controls. Many recommendations for the implementation of the "design-out" strategy are available from previous research, for example, some of which are: increasing designer knowledge of safety; incorporating construction safety knowledge in the design phase, making design for safety tools and guidelines; or mitigating designer liability exposure (Gambatese, Behm, & Hinze, 2005).

4.6 CONCLUSIONS

Electrocution is among the critical four leading causes of worker deaths in the construction sector, which contains 42.1% of overall electrical fatalities in 2012. A primary mission of occupational safety and health (OSH) research is to identify accident mechanisms and causation. The author interpreted such mechanisms of an electrical accident as a chain of decision mistakes throughout the entire workplace process, and attempted to analyze the decision-making chain. A decision is affected by both internal influence from the maker self and external influences from the circumstances. The "on-off" nature of construction industry highlights the importance to identify the context of influences for a decision-making chain. To express such context of influences, the researcher introduced the concept of "feature of work" (FOW) from construction quality control (QC) and re-defined it as a group of distinctive activities possessing higher OSH risks and hence requiring particular attentions. The analysis methods are Exhaustive CHAID and IDEF-0 diagrams. Data used in this study were mined from NIOSH's FACE investigation reports (1989-2012), since coded surveillance data do not provide sufficient details.

Findings identified five features of work associated with electrical hazards and developed a diagram of decision-making chain for each FOW. The five features of work are the Construction of utility systems (FOW-1), Equipment positioning (FOW-2), Construction of electrical systems (FOW-3), Construction of building enclosures (FOW-4), and Materials transportation (FOW-5). Among them, FOW-1 and FOW-3 are electrical works and the other three are non-electrical works.

Specifically, findings suggest that FOW-1 contains high likelihood of failure in de-energizing or grounding power lines; and causes high severity with more than half of fatalities being dead on arrival (DOA) or dead at the scene (DATS). The decision-making chain includes four critical decision points: FOW-1-1 ("onsite hazard survey"), FOW-1-2 ("de-energize power lines"), FOW-1-3 ("choose PPE"), and FOW-1-4 ("work on utility"), as previously mapped in Figure 4-5. The two constraints significantly influencing decision making are insufficient collaboration and technology.

FOW-2 contains high likelihood of failure due to improper use of tools and machinery; and causes high severity of more than two-thirds fatalities being DOA/DATS. The decision-making chain includes four critical points: FOW-2-1 ("onsite hazard survey"), FOW-2-2 ("de-energize power lines"), FOW-2-3 ("choose equipment"), and FOW-2-4 ("position equipment"), as previously mapped in Figure 4-6. The two constraints significantly influencing decision making are the lack of appropriate equipment and inadequate funding.

FOW-3 contains high likelihood of failure in lockout/tagout; and causes medium-to-high severity of almost half of fatalities being DOA/DATS. The decision-making chain includes four critical points: FOW-3-1 ("onsite hazard survey"), FOW-3-2 ("disconnect"), FOW-3-3 ("choose PPE"), and FOW-3-4 ("electrical work"), as previously mapped in Figure 4-7. The two constraints significantly influencing decision making are the lack of professional training and policy enforcement.

FOW-4 constrains high likelihood of failure due to lacking basic electrical knowledge; and may cause critical severity of more than half fatalities being DOA/DATS. The decision-making chain includes three critical points: FOW-4-1 ("onsite hazard survey"), FOW-4-2 ("insulate"), and FOW-4-3 ("work on roof and facade"), as previously mapped in Figure 4-8. The two constraints significantly influencing decision making are insufficient OSH knowledge and collaboration.

FOW-5 constrains high likelihood of failure in worksite surveying; and may cause critical severity of more than half fatalities being DOA/DATS. The decision-making chain includes four critical decision points: FOW-5-1 ("onsite hazard survey"), FOW-5-2 ("set distance"), FOW-5-3 ("operate machine"), and FOW-5-4 ("move materials"), as previously mapped in Figure 4-9. The three constraints significantly influencing decision making are insufficient OSH knowledge, police enforcement, and collaboration.

Findings also reflect a need for the interventional strategies such as prevention through design (PtD), showing that an earlier intervention decision mitigates better and has a greater impact; and thus the author advocates the implementation of a "designing safety in" and "designing hazards out" strategy for stakeholders in the AEC industry. Such a strategy is due to findings that many decision-making constraints are beyond the scope that construction workers can handle.

This work promotes electrical safety for construction workers through the lens of decision making. Outside of the findings, this work also contributes to the scholarly body of knowledge by introducing a decision-making chain which integrates decision-tree model and function modeling methods. Such a comprehensive approach is applicable to other safety research in the construction area, especially in risk mitigation and management.

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CHAPTER 5.

CONTROL MEASURES OF ELECTRICAL HAZARDS: AN ANALYSIS OF CONSTRUCTION INDUSTRY

Abstract: The construction industry has adopted control measures of electrical hazards for decades, however construction workers are still electrocuted in the workplace every year. This problem leads to a need for assessing the quality of control measures. The goal of this study is to assess the control measures of electrical hazards using a perspective of hierarchy of controls (HOC). HOC counts control measures of five levels in descending effectiveness, which are Elimination, Substitution, Engineering, Administration, and PPE. This study uses a mixed methods approach of narrative text analysis and statistical analysis in examining 486 NIOSH recommend controls from fatality investigations. Findings reveal that behavioral controls remain prevalent in electrical hazard mitigation even though the knowledge of construction safety and health has increased in the past decades. This study also finds that effectiveness of controls is not statistically different by construction type nor occupation. Proposing a solution, the author suggests that construction managers strictly stick to HOC rules by giving priority to higher level of controls and highly recommend that the U.S. construction industry upgrade its prevention strategy by introducing more technological innovations and encouraging prevention through design (PtD) strategies.

Keywords: Electrical hazards, control measure, construction industry, hierarchy of control, injury prevention, fatality investigation, FACE, electrocution, tag cloud.

5.1 Introduction

Literature shows that electrical-accident-related occupational injuries are disproportionate in construction compared to any other production sectors (Suárez-Cebador et al. 2014; Zhao et al. 2014). In the United States, the Occupational Safety and Health Administration (OSHA) named electrical hazards as one of the fatal four hazards to construction safety and health. Electrical hazards have been studied and corresponding mitigating measures have also been adopted for decades; however, construction workers still get electrocuted in the workplace every year.

Electrical hazards are well known and believed to be controllable (Kleiner et al. 2008) and therefore a need arises for assessing effectiveness of existing control measures. However, there is little to no research on such assessment of control measures of electrical hazards in construction. To bridge this gap, the present study attempts to address the problem of electrocution with a goal of ultimately minimizing workers' exposure to hazards.

In risk mitigation practice, performance evaluation often uses a hierarchy of control (HOC) standard to estimate a protection's effectiveness. As Figure 5-1 illustrates, HOC categorizes control measures into five primary levels in descending sort of effectiveness. The five levels (in a top-down order) are Elimination, Substitution, Engineering, Administration, and Personal protective equipment (PPE). Elimination is the first-level (most effective) hazard control that can remove the hazard all together. Elimination can be obtained by changing a work process in a way that will get rid of a hazard; for example, disconnecting electrical circuits with the electricity source. Substitution is the second-level control that exchanges something non-hazardous (or less-hazardous) to workers in place of a hazard. For example, a non-toxic (or less toxic) chemical could be substituted for a hazardous one. Engineering is the third-level control that uses safeguarding technology to place a barrier to keep a hazard from reaching workers. For example, using non-conductive ladders in construction may help to isolate workers from power lines. Administration is the fourth-level control that changes workplace schedules, policies, or procedures. For example, implementing the lockout/tagout procedure may decrease probability of a worker being shocked. PPE is the fifth-level control that directly places protective equipment on workers' bodies. PPE examples include helmets, respirators, gloves, sleeves, goggles, and ear plugs.

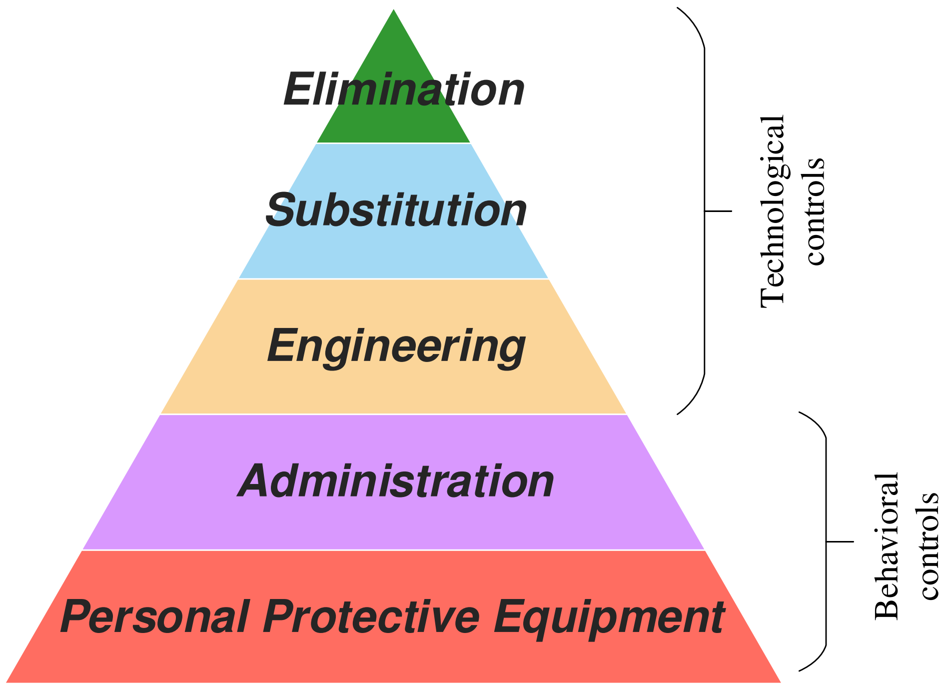


Figure 5-1. Hierarchy of controls.

The basic tenant of HOC is that control measures at a higher level are potentially more effective and protective while require more effort for implementation. The top three levels of control (shown in Figure 5-1) are classified as technological controls in that they act on changing the physical work environment; while the bottom two levels represent behavioral controls in that they seek to change the way people work. The Centers for Disease Control and Prevention (2014) explains the hierarchy as follows:

- *Elimination* and *Substitution* are the most effective at reducing hazards. They tend to be the most difficult to implement in an existing process while may be less expensive and less difficult for a process at the design stage.
- *Engineering controls*, if well designed, are highly effective in protecting workers and are typically independent of worker interactions. The initial cost of engineering controls is often high while the long-term operating cost is frequently low, or can even provide a cost savings in some instances.

- *Administrative controls* and *Personal Protective Equipment (PPE)* are frequently used with existing processes but have proven to be less effective than other measures. The initial cost may be relatively low while the long-term cost to sustain can be high. These measures require significant effort by the affected workers and do not well control hazards.

The strategy of learning from failures is based on the idea that risk mitigation measures often arise from accidents. Such an effort for risk mitigation is the national institute of occupational safety and health's (NIOSH) investigations of fatality assessment and control evaluation (FACE). Each FACE investigation contains non-routinely-analyzed elements in its report that allows for identification of factors that contribute to a fatal incident (Bunn et al. 2008). From the perspective of research, FACE has unique merit in the recommendations for prevention provided at end of each investigation. NIOSH safety professionals who wrote the reports suggest corresponding control measures in these recommendations based on their investigations. As a result, the NIOSH recommendations are considered to be a good resource for research of accident analysis and prevention. Kunadharaju et al. (2011) examined NIOSH recommendations from firefighter fatality investigations and generalized accident causes and corrective actions. Zhao et al. (2014) analyzed 132 electrocution reports and listed the top-cited NIOSH recommendations for electrocution prevention (See Table 5-1). Based on that finding, Zhao et al. (2014) recommended an enhancement of hazard awareness through safety training as a central part of prevention strategies. Nevertheless, previous studies did not evaluate the quality of resulting control measures, which may influence the reliability of implementation and performance.

Table 5-1. NIOSH recommendations for electrocution prevention (used with permision from Zhao, Thabet, et al., 2014).

NIOSH Recommendation	Pct. (%)
Adequate safety training and periodic specialized electrical safety training programs should be implemented to enhance the electrical hazard cognition and the avoidance of unsafe conditions in workplace.	62.9

Well-designed non-conductive personal protective equipment, communication equipment and supporting equipment should be provided and enforced to workers in workplace.	47.7
An electrical hazard survey should be conducted at jobsite to identify potential electrical hazards and intervention measures before work.	47.7
Compliance with safety procedures that required by existing federal and state standards and regulations should be ensured, such as the proper grounding, minimum clearance and lock-out/tag-out procedures.	42.4
Power lines should be de-energized or insulated before all works start.	34.1
On-site safety procedures, safety meeting and safety inspection should be enforced at construction site on a routine base.	33.3
Electrical safety procedures and preventions should be thoroughly considered and improved at the construction planning stage.	17.4
Guarding co-workers, warning signs and the supervisory guidance should be ensured on site.	13.6

FACE reports are narrative text in nature, which allows researchers to extract desired information using a method of narrative text analysis (NTA). Compared to coded surveillance data, the narrative text is believed to have added value (McKenzie et al. 2010) in the following three aspects: a) the identification of cases through alternative classification schema; b) the identification of sequential chain-of-event information; and c) the identification of systematic errors. As a result, many researchers have studied narrative text data in pursuit of occupational safety and health (OSH) in construction (Kemmlert and Lundholm 2001; Smith et al. 2006) and other industries (Bentley et al. 2005; Fordyce et al. 2007; Lincoln et al. 2004). The expected outcomes may identify (a) the effectiveness of adopted control measures; (b) the specific prevention strategies; and (c) the discrepancies of control measures among construction types, occupations, and electrical conditions, and the trend of changes over time.

5.2 Data source

FACE reports prove to be an eligible data source for OSH research. FACE reports have contributed to the formulation and dissemination of diverse strategies for OSH injury control (Higgins et al. 2001). This data source contains uncommon yet important information in the narrative texts, although they contain similar inclusion criteria with coded surveillance data sources, e.g., CFOI (Hammond et al. 2012). As a result, many prior studies have selected FACE reports as data source. For example, Cohen et al. (2006) examined FACE reports and concluded accident characteristics and resulting strategies needed to protect workers. Further, Kunadharaju et al. (2011) examined FACE reports and highlighted effective protection strategies for firefighters.

FACE reports, as a secondary data source (Boslaugh 2007), are beneficial for OSH research based on three strengths. First, FACE reports represent a high level of accuracy based on NIOSH investigators' expertise and professionalism. Second, national-scale data across historical periods of time enable researchers to reflect the entire industry's trends over time. Third, accident data collection is extremely difficult since an accident cannot be designed or manipulated in a laboratory, requiring continuous inputs led by a national organization (i.e., NIOSH).

This work continued previous inquiry on fatality investigations while expanding it to the area of control measures. This study's data were 486 NIOSH recommendations for prevention that were drawn from 134 FACE reports from 1989 to 2012 of electrocution at the construction site. As previously stated in the introduction section, this work focuses on recommendations of appropriate control measures included at the end of FACE report by NIOSH investigators.

5.3 ANALYSIS METHODS

Setting Zhao et al. (2014) as a point of departure, this study uses a mixed methods approach that integrates qualitative and quantitative analyses to explore control measures of electrical hazards.

5.3.1 Qualitative analyses

This study uses narrative text analysis (NTA), a method that extracts and explores useful hidden information through analytical techniques (e.g., natural language processing) turning text into data. Specific NTA techniques include information retrieval, lexical analysis to study frequency distributions, pattern recognition, tagging/annotation, information extraction, text mining, visualization and predictive analytics. Typical NTA tasks include text categorization, text clustering, concept/entity extraction, granular taxonomies production, sentiment analysis, document summarization, and entity relation modeling (Cohen and Hunter 2008).

NTA has a high degree of sensitivity and is able to provide supplemental information on additional unknown risk factors (Bunn et al. 2008). Based on previous work, NTA provides appropriate methods for OSH research in the architecture, engineering, and construction (AEC) industry. Bondy et al. (2005) suggested NTA could guide investigators to explicitly consider human, organizational, and environmental factors, and then foster more complete descriptions of factors contributing to the construction injury. Glazner et al. (2005) used NTA in analyzing 4,000 injury reports for the construction of the Denver International Airport, and concluded that narrative descriptions from injury reports can provide detail on circumstances surrounding injuries and identify factors contributing to injury. Using NTA, Dement et al. (2003) analyzed the occurrence of nail gun-associated injuries among construction workers and identified preventable work-related factors associated with these injuries. Through coding text descriptions, Lipscomb et al. (2004) identified circumstances surrounding falls, and suggested that NTA enables the exploration of factors not identified at the time of data collection and may result in better understanding of the context where injuries occur. Lombardi et al. (2005) utilized a hybrid narrative coding method to determine activities and circumstances proximal to a welding related occupational eye injury, and concluded that NTA can distill valuable information to supplement traditional epidemiologic analysis.

Specifically, a task of using NTA in this work is text categorization, coding each piece of recommend control measure in terms of the hierarchy of control (HOC). HOC is well established in work safety and health and consists of five levels: Elimination, Substitution, Engineering, Administration, and PPE (previously detailed in the introductory section). In this way, researchers can categorize each recommended control into a HOC level and then assign it with a score from 1 to 5 to represent the HOC levels from PPE to Elimination. For example, a NIOSH recommendation that "doing a hazard survey prior to working on a pole" is categorized into an HOC of administration and then assigned with a HOC score of 2. It is also important to note that a safety expert panel, consisting of university faculty and OSHA professionals, has supervised the NTA process and reviewed the results for research validity and reliability. These experts have more than ten years of experiences in the teaching, research, or administration of construction safety.

Another task of using NTA in this study is text clustering through tagging/annotation and word frequency techniques. NIOSH recommendations may not be stated exactly in a same way even if they have the same meaning (Zhao et al. 2014). In such consideration, a method of text clustering becomes necessary for the researcher to accurately identify the prevention strategies behind texts. Especially, analysis results were visualized through a novel technique of textual tag clouds. In a tag cloud, the font size of each tag depends on the number of instances that are associated with tagging/annotation within a context (Zhang et al. 2014). As a result, a tag cloud is capable of representing the entity of control measure hidden in the textual contents and is also able to indicate specific prevention strategies. The author used NVivo software (Bazeley 2007) to perform the text clustering and generate tag clouds. This software is advanced in that it is able to automatically match similar words such as synonyms.

5.3.2 Quantitative analyses

This work used statistical analysis methods in three specific areas. First, the researcher performed descriptive analysis to provide an overview of all data. Second, the researcher performed ANOVA and t-test to compare the data by factors of Construction type, Occupation, and Electrical condition. The three factors have been identified as important parameters for electrical safety research by prior studies (Zhao et al. 2014), and might result in useful findings for hazard mitigation. Specifically, values of the factor "Construction type" include residential, commercial, industrial, and heavy & civil construction; values for the factor "Occupation" include electrical occupations and non-electrical occupations; and values of the factor "Electrical condition" include high voltage (higher than 1000 volts) and low voltage (1000 volts or lower, International Electrotechnical Commission 2002). Third, the author performed linear regression analysis to explore trends in a control measure's change over time. The data (FACE investigations) range from 1989 to 2012. In addition, the author used SAS software to conduct the quantitative analyses.

Two variables were computed in the quantitative analyses. One is HOCS, namely the HOC score. It represents the average effectiveness of hazard controls on a scale of 1-5. Based on the definition of HOC, a higher score means a more effective control. The other is RECM, namely the number of recommendations. It indicates the amount of known control measures and is a proxy for the amount of knowledge of electrical hazard mitigation.

5.4 RESULTS

5.4.1 Overall descriptive results

Table 5-2 summarizes the descriptive analysis results of HOCS and RECEM. From 486 NIOSH recommend controls, the overall HOCS mean was 2.51 with a minimum HOCS of 1 and a maximum HOCS of 5. It indicates that these control measures span across all HOC levels (from PPE to Elimination) while the average HOC level is of behavioral control (HOCS < 3). The per-case HOCS mean was 2.52 which is similar to the overall HOCS, suggesting little variance among cases. The per-case RECM mean was 3.60 with a minimum of 2 and a maximum of 8. It indicates that for each electrocution there are on average three and at least two specific measures to control electrical hazards.

Table 5-2. Descriptive analysis results.

Variable	N	Mean	Std. Deviation	Min.	Max.
Overall HOCS	486	2.51	1.053	1.00	5.00
Per-case HOCS	134	2.52	0.544	1.33	4.00
Per-case RECM	134	3.60	1.236	2.00	8.00

Figure 5-2 shows the tag cloud for all cases. In the cloud, words "tool" and "training" have the biggest font size, which indicates two key control measures, i.e., tool design and improvement (as an engineering control) and safety training (as an administrative control). This observation gives evidence of a previous finding that the average HOC level is behavioral control. The tag cloud also visualizes many other control measures, for example, conducting an "onsite survey", "de-energizing" electricity sources, strictly "complying" to "rules" and regulations, keeping safe "clearance" to electrical hazards, properly wearing "PPE", executing safety "inspection", using precautions on conductive "materials", establishing safety "programs", routinely conducting safety "inspections", setting "guarding" persons or signs, and "consulting" third-party professionals.

Figure 5-2. Tag cloud for all cases.

5.4.2 Comparison by construction type

Table 5-3 shows results of ANOVA comparison among cases with residential, commercial, industrial, and heavy and civil construction. Results of HOCS or RECM did not identify any significant differences (with a 95% confidence level) among these construction types, suggesting that the effectiveness and knowledge of control measures do not significantly differ by construction type. Surprisingly, the finding contradicts a common belief that safety professionals might more effectively mitigate electrical hazards in residential projects due to less complicated electrical systems.

Table 5-3. Results of ANOVA by construction type.

Variable	F	Sig.	N	Construction type	Mean	Std. Error	Lower 95%	Upper 95%
HOCS	0.810	0.490	134	Residential	2.43	0.081	2.265	2.586
				Commercial	2.56	0.122	2.319	2.801
				Industrial	2.49	0.157	2.181	2.805
				Heavy & civil	2.59	0.072	2.447	2.733
RECM	0.261	0.853	134	Residential	3.51	0.186	3.143	3.879
				Commercial	3.65	0.279	3.098	4.202
				Industrial	3.83	0.360	3.121	4.546
				Heavy & civil	3.67	0.165	3.340	3.993

Tag clouds from Figure 5-3 illustrate the different emphases of specific control measures among various construction types. Control measures for residential construction focus on “tool” and “onsite survey”, which suggest a prevention strategy on equipment supply and hazard awareness. It also suggests that homebuilders are often small and medium-sized firms which may not provide sufficient tools for workers to effectively deal with electrical hazards (e.g., nonconductive ladders). Control measures for commercial construction focus on safety “training”, which is primarily a prevention strategy based on administration. Commercial construction often involves complicated electrical systems and hence requires workers to obtain more electrical knowledge. Control measures for industrial construction focus on the establishment and implementation of safety procedures, especially the procedure of “lockout/tagout”. Its prevention strategy is also administration-based. Findings demonstrate multiple focuses of control measures for heavy & civil construction, of which the major ones are “PPE”, safety “training”, “procedure design”, and effective “deenergizing” methods. Prevention strategies broadly cross multiple control hierarchies from PPE to Elimination.

(a) Residential construction

(b) Commercial construction

(c) Industrial

(d) Heavy construction

Figure 5-3. Tag clouds for cases by construction type

5.4.3 Comparison by occupation

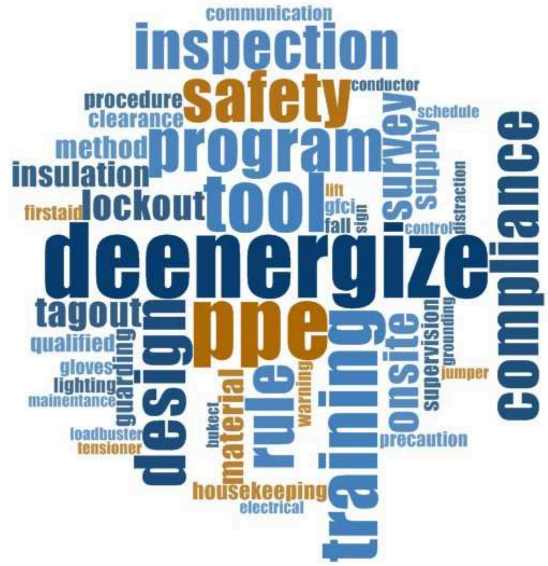
Table 5-4 shows results of t-test between cases associating electricians and non-electricians. The results suggest the HOC scores between the two occupational groups are not statistically different (with an α=0.05 significance level). Such a finding seems contradictory to a common belief that electricians should be able to effectively control electrical hazards since such professions (e.g., the line installer, electrician) acquire more electrical knowledge and practical experience. Findings from the present analysis question whether these beliefs might not be correct. In contrast, results from the t-test identified a significant difference in RECM ($t = 3.842, p < 0.001$) between the two occupational groups, indicating that safety practice has slightly greater amount of intervention means for non-electrical workers. The researcher would interpret this group's higher average RECM as attributed to the greater amount of involved non-electrical professions and their tasks, as well. Typically involved non-electrical professions include: construction laborers, roofers, masons, carpenters, painters, truck drivers, crane operators.

Table 5-4. Results of t-test by occupation

Variable	t	Sig.	N	Occupation	Mean	Std. Error	Lower 95%	Upper 95%
HOCS	-0.812	0.418	134	Electrician	2.56	0.071	2.424	2.705
				Non-electrician	2.49	0.063	2.363	2.612
RECM	3.842	<0.001*	134	Electrician	3.19	0.153	2.883	3.490
				Non-electrician	3.97	0.136	3.705	4.242

Note: symbol * denotes a significant difference with a 95% confidence level.

Tag clouds from Figure 5-4 show the different emphases of specific control measures between cases of electrical and non-electrical occupations. The emphasis of controls for electricians includes "de-energizing" electricity and properly wearing "PPE", suggesting a prevention strategy that integrates hazard elimination (the most effective) and personal protection (the least effective). The integrated strategy often results in compromised effectiveness for overall protective performance, which can consequently explain why its mean HOCS is only 2.56. In contrast, the emphasis of controls for non-electricians includes enhancing hazard awareness ("onsite survey"), using proper equipment ("tool"), and obtaining OSH knowledge ("training"), suggesting a prevention strategy that is primarily reliant to administration and engineering HOCs. The HOCS variable mean of 2.49 (resulting from previous analysis) confirms such a strategy and implies the insufficiency of engineering controls.



(a) Electrician

(b) Non-electrician

Figure 5-4. Tag clouds for cases by occupation.

5.4.4 Comparison by electrical condition

Table 5-5shows results of t-test comparison between cases related to high and low voltage. The results identified a significant difference of HOCS (t= -2.498, p = 0.014) that control measures of high-voltage hazards are statistically less effective than those of low-voltage. This finding reflects a fact that low-voltage electrical hazards can be more effectively controlled by construction workers, compared to high-voltage ones. However, the t-test results did not identify any significant difference of RECM between cases with the two electrical conditions (with a 95% confidence level).

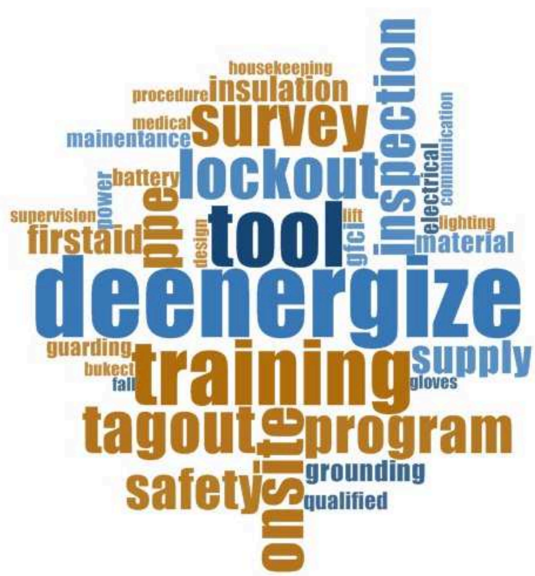
Table 5-5. Results of t-test by electrical condition

Variable	t	Sig.	N	Electrical Condition	Mean	Std. Error	Lower 95%	Upper 95%
HOCS	-2.498	0.014*	134	High voltage	2.47	0.054	2.364	2.579
				Low voltage	2.74	0.095	2.557	2.931
RECM	1.751	0.082	134	High voltage	3.71	0.122	3.469	3.953
				Low voltage	3.28	0.213	2.860	3.703

Note: symbol * denotes a significant difference with a 95% confidence level.

Tag clouds from Figure 5-5 demonstrate the different emphases of specific control measures between cases with high and low-voltage conditions. The results indicate multiple emphases for controlling high-voltage hazards such as "tool" design and improvement, hazard awareness ("onsite survey"), and safety "training"; while its prevention strategy is largely based on administration and engineering HOCs as well. In contrast, the primary measures in controlling low-voltage hazards, such as successful insulation ("deenergize"), suggests an elimination-based prevention strategy. This observation provides evidence of previous findings from the HOCS variable t-test that control measures of low-voltage hazards are more effective.

(a) High voltage



(b) Low voltage

Figure 5-5. Tag clouds for cases by electrical condition.

5.4.5 Trends of change over time

Figure 5-6 demonstrates the result of linear regressions of HOCS and RECM (as response variables) by date (as a predictor variable). The linear fit lines (in red) indicate a significant declining trend of HOCS ($F = 0.355$, $p = 0.046$) and a significant rising trend of RECM ($F = 7.346$, $p = 0.008$). In the charts, kernel smoother curves (in green) are also provided to visualize weighted local changes over the period from the beginning of 1989 to the end of

2012. Coupling these results, it suggests a tiny decrease of the effectiveness of recommended control measures in the past 20 years and, on the other hand, suggests a small increase of the OSH knowledge on electrical hazards.

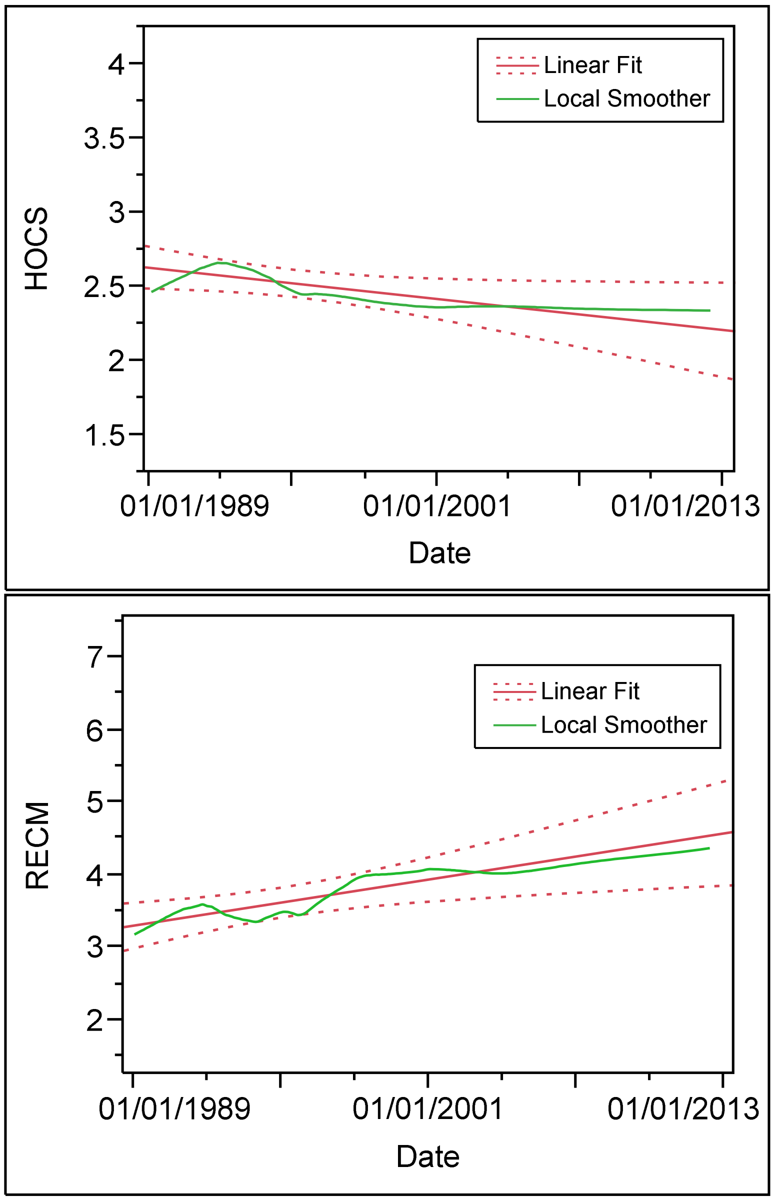


Figure 5-6. Charts of linear regression by date.

To further explore the change of specific control measures, the researcher sets year 2000 as a cut-off and compared the control contents between the two split periods. Shown in Figure 5-7, from 1989 to 2000, the emphasis of controls includes safety "training", "onsite survey", and using proper "tools". Its prevention strategy was largely based on administration. From 2001 to 2012, the emphasis of controls became more inclusive, covering proper “tools” usage, electricity cut-off (“deenergizing”), safety “training” enhancement, work “design” improvement, “safety programs” establishment, and strict rules “compliance”. Its prevention strategy extended across multiple HOC levels. Comparatively, the large number of tags in the cloud of “2001-2012” indicates a boost of OSH knowledge in prevention, which confirms prior regression results. A large portion of the emerging measures, however, were of behavioral controls (e.g., rules compliance, safe work procedures, or inspections) suggesting that they might hinder overall performance. This finding can, to some extent, explain why the average HOC score has a declining trend over time.

(a) 1989-2000

(b) 2001-2012

Figure 5-7. Tag clouds for cases by time.

5.5 DISCUSSION

OSHA defines a hazard as an OSH threat that may cause worker injuries if not well controlled. Researchers believe that all known hazards, including electrical hazards, are controllable and solutions are rooted in how effectively they are controlled. The theory of the hierarchy of controls provides us a tool to assess the effectiveness of control measures. Findings from this study revealed that control measures of electrical hazards are still largely reliant on behavioral controls (the average HOC score is 2.52 out of 5) even though the knowledge of OSH continues to increase over time. Therefore, the construction management, regardless of residential, commercial, industrial, and/or heavy industries need to pay close attention to electrical hazards.

The standard of hierarchy of controls requires that higher level of controls must be first applied to protect workers unless that level of control is proven infeasible. A paradox when using high-level controls is that it often leads to an increase of expense, crew, time, or work difficulty. Compared to the high mortality rate in electrical accidents (Zhao et al. 2012), these increments cannot be an acceptable excuse for implementing insufficient levels of control, though. This HOC rule must be strictly obeyed in the management of construction projects. In other words, whenever possible, priory effort must be taken to eliminate an electrical hazard, especially those in low-voltage. Some of the eliminating measures are de-energizing the source of electricity, properly grounding, or insulating the source.

Following the HOC standard, personal protective equipment is the last resort and should not be considered unilateral in its hazard prevention. The purpose of PPE is to reduce workers' exposure to a hazard while PPE cannot get rid of the hazard. Due to such an inherent defect, PPE is unable to provide workers complete safety. First, PPE may be inadequate or fail, and when it happens the worker will not be protected at all. Improper maintenance or improper use may largely lead to such failures. Second, PPE may be uncomfortable to wear, which places unexpected physical pressure on workers and may deduct their productivity. A number of FACE cases show that victims took off their rubber gloves and sleeves at the job-site due to discomfort and feeling uneasy to work. This problem can be worse when the wearer works at an exposed construction site in hot weather. Third, PPE can protect the wearer only and the hazard can still injure other individuals who do not wear PPE by accident. Overall, a worker should never work in the vicinity of a live electrical hazard even if wearing PPE, unless no higher level of control is available to reduce the hazard to an acceptable level.

Moreover, insufficient OSH mitigation is not only for controlling electrical hazards but exists throughout the U.S. construction industry. A study of 23 construction projects with 238 interviews concluded that the average HOC score for U.S. construction was 2.48 (Wakefield et al. 2014). That study involves a variety of OSH hazards in construction and reveals similar findings that behavioral controls are prevalent in OSH in the industry. Their identified typical behavioral controls, similar to the findings as well, include enforcing safety rule compliance, performing onsite hazard surveys prior to work, inspecting equipment in a regular basis, sufficiently training workers of hazard awareness, establishing standard operating processes (SOP) in policy, and installing warning signs.

Overall, findings highly suggest a necessity for the whole industry to upgrade its prevention strategy by introducing more technological controls. This goal can be achieved through multiple pathways. One potential path is through technological innovations. For example, a remote-controlled crane can greatly alleviate an operator's exposure to overhead power lines. Another potential path is through the prevention through design (PtD). PtD aims to eliminate hazards or control OSH risks at acceptable levels by implementing a strategy of "designing hazards out" at the early planning stage. In other words, PtD requires early inputs from all stakeholders of a construction project. As a result, most PtD solutions are highly effective with an average HOC score of 4.2 (Wakefield et al. 2014). Unfortunately, U.S. designers often isolate themselves from OSH in consideration of possible liabilities with "means and methods" (Saunders et al. 2014). In contrast to the U.S, the Australia construction industry benefits from its widespread PtD implementations, resulting in an average HOC score of 3.69 (Wakefield et al. 2014). In Australia, legislation determines responsibilities based on the "practical" relationship rather than contractual agreements, which means that the duty of care can be shifted to any stakeholders who expose workers to OSH risks (Saunders et al. 2014).

5.6 Conclusions

Globally, occupational injuries due to electrocution are disproportionate in the construction industry. In the United States, OSHA named electrical hazard as one of the fatal four hazards to the construction safety and health. The industry has adopted corresponding control measures of electrical hazards for decades, however this hazard still caused many deaths of construction workers every year. This problem leads to a need for assessing the quality and effectiveness of control measures. However, there is little to no research into control measures for electrical safety in construction. Therefore, the present work aims to analyze existing control measures of electrical hazards by applying an approach of the hierarchy of controls. The hierarchy of controls categorizes control measures into five levels of descending effectiveness, which are Elimination, Substitution, Engineering, Administration, and Personal protective equipment (PPE). Among the five HOC levels, the former three are classed as technological controls as they can change hazards; while the latter two are behavioral controls as they are unable to change hazards but only limit workers' exposure by changing the way they perform.

Specifically, this study used a mixed methods approach of narrative text analysis and statistical analysis and examined 486 NIOSH recommended controls from 134 fatality investigations. Findings reveal that current control measures of electrical hazards remain largely reliant on behavioral controls even though the knowledge of OSH has increased in the past decades. The effectiveness of controls is not found to statistically differ among various construction types nor workers' occupations. The finding is confirmed by other studies by suggesting that administrative controls remain prevalent throughout the industry's prevention strategy. Examples of such controls are enhancing safety training, establishing safety policies, and performing onsite surveys.

Findings also suggest that construction management should strictly abide by the HOC standard by giving priority to a higher level of control unless it is proven infeasible. In practice, the first effort must be an attempt to eliminate electrical hazards, for example, by disconnecting, grounding or insulating the electricity source. The findings also highly recommend that the U.S. construction industry upgrade its prevention strategy by investing in more technological innovations and encouraging prevention through design.

Outside of the OSH findings, this study also developed and demonstrated a novel method for assessing the performance of OSH control measures. The assessment is based on the use of the hierarchy of controls and may contribute to more reliable insight of the quality of OSH risk mitigation. Further, this method is applicable to safety research in industries other than construction.

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CHAPTER 6.
CONCLUSIONS

6.1 SUMMARY

Internationally, construction is considered a hazardous industry with a disproportionate amount of fatal and non-fatal accidents for its workers as compared to other industries. Electrocution is among the “fatal four” in the US construction industry, according to the Occupational Safety and Health Administration (OSHA).

For decades, injuries due to electrocution continue to be a serious problem that has impacted the United States construction industry. Workers in the U.S. construction industry encounter the highest risk from electrical injuries compared to any other industrial sector. CFOI records show that on average electrical fatalities in construction industry accounted for 47.9% of electrocutions from 2003 to 2012. The fatalities include both electrical workers and non-electrical workers. The large electrocution share and smaller employment share in construction results in a relatively high electrocution rate. In 2011 the electrocution rate for U.S. construction was 12.2 per one million full-time construction workers while it was 1.3 per one million full-time workers across all industries. The electrocution rate in construction is as much as 9.4 times of the average rate across industry. Such a rate necessitates research into improving safety systems and reducing fatalities for this type of work and industrial sector.

Losses due to electrical injuries are in both terms of physical trauma and financial expense. Most accidents involving electric shocks are traumatic and cause severe tissue damage or death. Electrical injuries have led to mortality rates as high as 15%. Meanwhile, the average cost due to electrocution is $948,844 per case ranking the highest per-fatal-case cost in construction, while the cost of nonfatal injury is approximately $86,829 per case ranking the 2nd highest per-nonfatal-case cost in private industry and almost double the cost of average nonfatal-case loss in construction. These costs include direct medical costs, indirect losses in wage and household productivity, as well as an estimate of the quality of life costs due to injury.

Existing research and industry practice has attempted to provide insight into the electrical injuries for construction safety however problems still exist. One problem is a lack of understanding of causation mechanisms surrounding fatal accidents by electrocution in a systems perspective. Interpretations of surface causes from statistics are limited in their presentation of accidental mechanisms and they are often insufficient for explaining associations and interactions within the whole work system. In fact, the mechanisms are largely contextual and are hence different based on their contexts. Another problem is a disconnection between the mechanism of fatal electrocution accidents and the associated control measures, which may lead to less effective prevention in construction. Such a lack of hierarchical prevention strategy may result in disconnect between fatal accidents and prevention techniques and ultimately may lower the impact of controls. Horizontally, control measures are not holistic and current prevention strategies rarely confine them to a specific context. Vertically, control measures are hierarchical and equal treatment does not lead always to effective prevention strategies.

This dissertation aimed to address aforementioned problems in construction safety with three specific objectives. The first objective was to establish a sociotechnical system model that reflects the electrocution occurrence in the U.S. construction industry and identify the associations among its internal subsystems. The second objective was to determine specific electrocution scenarios and associated mechanism constraints. The third objective was to examine hierarchy of control measures and determine appropriateness through an analysis of electrocution investigation recommendations.

This work continued the line of query that learning from respective fatalities presents one possible solution for diagnosing and fixing current safety mistakes, because learning from failure is believed to be an effective means to counteract system failures, some of which may cause fatal injuries. As a result, this work analyzed NIOSH's FACE fatality investigations of construction workers due to electrocution. Specifically, the author followed his Master's research as a point of departure to the dissertation. The outcome of his prior research (Zhao, Thabet, McCoy, and Kleiner, 2014) revealed typical features of electrical accident fatalities in construction and provide common electrical safety challenges on construction sites (see Appendix A).

Two points of limitations exist in this work. The first one is pertaining to the limited sample size, which might cause statistical error; however, the probability of error can be lowered through certain countermeasures. The other limitation is pertaining to the reliability of secondary data, i.e., FACE reports, which were human-compiled and might be subjective; however, this limitation was constrained by the NIOSH investigator's professionalism and expertise.

6.2 FINDINGS

First, findings from this work revealed three representative electrical injury STS patterns and their system interactions. (1) For residential construction, younger (age<40) male non-electrical workers die due to indirectly contacting high-voltage power lines or powered machines/tools, usually in Summer or Winter at outdoor workplaces. Employers often do not have written safety policies nor provide safety training programs. In this hazard system, organizational/managerial subsystem and its interactions with the other two subsystems have been identified as weaknesses while the internal and external environment is a threat. Based on the hierarchy of control, findings suggest a need for relevant administrative interventions. (2) For heavy construction, middle-aged (age 40-64) male electrical workers die due to directly contacting high-voltage power lines or electrical components, usually in Spring, Fall or Winter weekends at outdoor workplaces. These employers typically have written safety policies and provide safety training programs. In this STS, technological subsystem and its interaction with the personnel subsystem are considered as weaknesses while the environment is a threat. Findings suggest a need for relevant engineering and administrative prevention measures. (3) For non-residential construction, adolescent (age<20) male workers died due to directly contacting low-voltage electrical components or powered machines/tools at an indoor workplace. Personnel subsystem and its interactions with the technological subsystems are weaknesses. Findings suggest a need for substitution and administrative controls.

Second, findings identified five features of work associated with electrical hazards and developed a diagram of decision-making chain for each FOW. The five features of work are the Construction of utility systems (FOW-1), Equipment positioning (FOW-2), Construction of electrical systems (FOW-3), Construction of building enclosures (FOW-4), and Materials transportation (FOW-5). Among them, FOW-1 and FOW-3 are electrical works and the other three are non-electrical works. (1) FOW-1 contains high likelihood of failure in de-energizing or grounding power lines; and causes high severity with more than half of fatalities being dead on arrival (DOA) or dead at the scene (DATS). The decision-making chain includes four critical decision points: FOW-1-1 ("onsite hazard survey"), FOW-1-2 ("de-energize power lines"), FOW-1-3 ("choose PPE"), and FOW-1-4 ("work on utility"), as previously mapped in Figure 4-5. The two constraints significantly influencing decision making are insufficient collaboration and technology. (2) FOW-2 contains high likelihood of failure due to improper use of tools and machinery; and causes high severity of more than two-thirds fatalities being DOA/DATS. The decision-making chain includes four critical decision points: FOW-2-1 ("onsite hazard survey"), FOW-2-2 ("de-energize power lines"), FOW-2-3 ("choose equipment"), and FOW-2-4 ("position equipment"), as previously mapped in Figure 4-6. The two constraints significantly influencing decision making are the lack of appropriate equipment and inadequate funding. (3) FOW-3 contains high likelihood of failure in lockout/tagout; and causes medium-to-high severity of almost half of fatalities being DOA/DATS. The decision-making chain includes four critical points: FOW-3-1 ("onsite hazard survey"), FOW-3-2 ("disconnect"), FOW-3-3 ("choose PPE"), and FOW-3-4 ("electrical work"), as previously mapped in Figure 4-7. The two constraints significantly influencing decision making are the lack of professional training and policy enforcement. (4) FOW-4 constrains high likelihood of failure due to lacking basic electrical knowledge; and may cause critical severity of more than half fatalities being DOA/DATS. The decision-making chain includes three critical points: FOW-4-1 ("onsite hazard survey"), FOW-4-2 ("insulate"), and FOW-4-3 ("work on roof and facade"), as previously mapped in Figure 4-8. The two constraints significantly influencing decision making are insufficient OSH knowledge and collaboration. (5) FOW-5 constrains high likelihood of failure in worksite surveying; and may cause critical severity of more than half fatalities being DOA/DATS. The decision-making chain includes four critical decision points: FOW-5-1 ("onsite hazard survey"), FOW-5-2 ("set distance"), FOW-5-3 ("operate machine"), and FOW-5-4 ("move materials"), as previously mapped in Figure 4-9. The three constraints significantly influencing decision making are insufficient OSH knowledge, police enforcement, and collaboration.

Third, findings also uncovered that current control measures of electrical hazards remain largely reliant on behavioral controls even though the knowledge of OSH has increased in the past decades. The effectiveness of controls is not found to statistically differ among various construction types nor workers' occupations. The finding is confirmed by other studies by suggesting that administrative controls remain prevalent throughout the industry's prevention strategy. Examples of such controls are enhancing safety training, establishing safety policies, and performing onsite surveys.

6.3 CONTRIBUTION

This dissertation has two forms of contribution to the body of knowledge. The first form of contribution comes to the content of safety knowledge. Findings from this research contribute broadly to the construction industry providing better demonstration of the mechanisms of electrocution and the relationships among contributing factors in construction; increasing the prevention efficiency for real-life practices; and building a basis for more innovative control measures in features of work. The other form of contribution comes to the methodological knowledge for safety research. This work applied a variety of innovative research methods in exploring construction safety and control measures. The methods include a macroergonomics-based triangulation approach for analyzing sociotechnical systems; a decision-tree-based decision-making chain approach for examining accident mechanisms; and also a hierarchy-of-control-based narrative text analysis approach for assessing prevention effectiveness. These systems-based methods are applicable to the safety research and risk management in areas of construction and beyond.

The dissertation also contributes to the construction industry's risk mitigation in terms of the "Research to Prevention" (R2P). This research revealed the existent of insufficient OSH mitigation throughout the U.S. construction industry, and recommends a need for the interventional strategies such as prevention through design (PtD). PtD represents an earlier intervention decision mitigates better and has a greater impact. For R2P, the author advocates the implementation of a "designing safety in" and "designing hazards out" strategy for stakeholders in the AEC industry. This research also recommends that construction management should strictly abide by the HOC standard by giving priority to a higher level of control unless it is proven infeasible. In practice, the first effort must be an attempt to eliminate electrical hazards, for example, by disconnecting, grounding or insulating the electricity source. Overall, the findings highly recommend that the U.S. construction industry upgrade its prevention strategy by investing in more technological innovations and encouraging prevention through design.

6.4 FUTURE WORK

Many future extensions of this work are possible. This research explored construction safety and control measures through electrical fatalities, though. One future research goal is to continue the current line of query while extending it to other fatal hazards of occupational safety and health in construction; for example, falling from the heights. Current literature thoroughly looks at the hazard while not using systems approaches, which are innovatively applied in the current research.

Another future research goal is to deeply investigate prevention strategies for electrical injuries. This work has revealed the work system weaknesses and mechanism constraints of current OSH practice. Based on such findings, further work may focus on the technological innovations for more effective control measures. The state-of-art building/construction technologies may provide possible direction for solution. For example, technologies such as building information modelling (BIM) or virtual reality (VR) provide possible direction for the improvement. Future research should develop a systematic process that integrates these technologies into OSH practice, alleviating the uncovered system weaknesses; and then validate the integration's performance and scalability. On the other side, future research should investigate the best practice for the implementation of prevention through design (PtD) strategies, in terms of institutional, organizational, managerial aspects.

APPENDIX A

ELECTRICAL DEATHS IN THE U.S. CONSTRUCTION: AN ANALYSIS OF FATALITY INVESTIGATIONS

This paper is referenced from the Introduction chapter in section 1.4, as a point of departure. This paper was published in the *International journal of Injury Control and Safety Promotion*, Volume 21, Issue 3, page 278 - 288. The paper can be located by the digital object identifier number (DOI) of 10.1080/17457300.2013.824002. The author included this paper with permission from the journal to be part of author's dissertation.

Electrical Deaths in the U.S. Construction: An Analysis of Fatality Investigations

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Abstract: Electrocution is among the "fatal four" in U.S. construction according to the Occupational Safety and Health Administration (OSHA). Learning from failures is believed to be an effective path to success, with deaths being the most serious system failures. This paper examined the failures in electrical safety by analyzing all electrical fatality investigations (N=132) occurring between 1989 to 2010 from the Fatality Assessment and Control Evaluation (FACE) program which is completed by the National Institute of Occupational Safety and Health (NIOSH). Results reveal the features of the electrical fatalities in construction and disclose the most common electrical safety challenges on construction sites. This research also suggests the sociotechnical system breakdowns and the less effectiveness of current safety training programs may significantly contribute to worker's unsafe behaviors and electrical fatality occurrences.

Keywords: electrical safety; construction; fatality investigations; accident prevention.

INTRODUCTION

The construction industry remains a dangerous product sector in fatality and injury world widely (Gholipour, 2004). In the United States, electrocution is among the "fatal four" in construction industry according to the Occupational Safety and Health Administration (OSHA). Contact with electricity ranks 4th in the top 10 accident events that lead to construction fatalities, following falls to a lower level, roadway vehicle incident, and being struck by object or equipment (see Table A-1). In 2011, 69 deaths were due to electrocution, accounting for 9.3% out of 738 construction fatalities (US Bureau of Labor Statistics, 2013).

Table A-1. Top 10 accidental events leading to construction fatalities in 2011

Accidental events	*N*	Pct. (%)
Falls to a lower level	255	34.6
Roadway vehicle incident	95	12.9
Stuck by object or equipment	73	9.9
Contact with electricity	69	9.3
Pedestrian vehicular incident	65	8.8
Crushed in collapsing structure, equipment or material	30	4.1
Non-roadway vehicle incident	25	3.4
Exposure to other harmful substance	26	3.5
Intentional injury by person	22	3.0
Caught in or compressed by equipment or objects	18	2.4
Misc.	60	8.1
Total	738	100

Note: Data source is from the Census of Fatal Occupational Injuries (US Bureau of Labor Statistics, 2013)

Also as shown in Table A-2, the electrical fatalities in the construction industry have been approximately as many as the sum of all other non-construction industries for years. During the recent nine years, the smallest proportion of electrical deaths that the U.S. construction engaged was 39.7%, indicating that among every five electrocutions at least two occurred in construction. On the contrary, the construction sector was involved in smaller proportions of fatality due to other top events. For instance, the U.S. construction industry incurred 38.4% of the overall falling fatalities, 8.6% of roadway fatal incidents and 15.3% of being-struck fatal injuries in 2011. In other words, the construction industry has the highest percentage of electrocution and its workers encounter the highest risk from electrical injuries in workplaces (Zhao, Thabet, McCoy, & Kleiner, 2012). Like many construction incidents, many of these are preventable.

The frequency of being killed by electricity in construction continues to be higher than the industry average. The electrocution rate is a measure of the number of deaths due to electrocution within a population in a given time period. For 1992 to 2002, Cawley and Homce (2008) claimed that the electrocution rate for construction was over five times that for all industry level. For 2003 to 2011, the electrocution rate for construction was 1.5 deaths per 100,000 full-time construction workers while the all industry average rate was 0.2 per 100,000 workers (BLS US Bureau of Labor Statistics, 2012; 2013). The construction electrocution rate has risen to be more than seven times that the average of all industry as a whole.

Table A-2. Electrical fatalities in construction and all other industries, 2003-2011

		2003	2004	2005	2006	2007	2008	2009	2010	2011
Construction Industry	N	132	122	107	126	108	89	89	76	69
	Pct. (%)	53.7	48.0	42.6	50.4	59.9	46.4	52.4	46.6	39.7
All other industries	N	114	132	144	124	104	103	81	87	104
	Pct. (%)	46.3	52.0	57.4	49.6	49.1	53.7	47.7	53.4	60.3
Total counts		246	254	251	250	212	192	170	163	173

Note: data source is from CFOI (US Bureau of Labor Statistics, 2013)

Losses due to electrical accidents in construction are significant in both physical and societal traumas. Electrical accidents involve electric shocks, electrical burns, arc blasts, of which most result in severe tissue damage or even mortality as high as 15% (Lee & Dougherty, 2003). In terms of financial expense, average losses due to electrocution were $948,844 per fatal case and $86,829 per nonfatal case, which respectively ranked the first highest per-fatal-case cost and the second highest per-nonfatal-case cost in construction (National Institute of Occupational Safety and Health, 2006; Waehrer, Dong, Miller, Haile, & Men, 2007).

Efforts to explore either electrical injuries or construction accidents have been undertaken by some researchers. Niskanen and Saarsalmi (1983) conducted a frequency analysis using different factors to investigate construction accidents; Haslam et al. (2005) examined construction accidents and distilled contributing factors based on both of the site-based and off-site based investigations; Hale, Walker, Walters, and Bolt (2012) explored the construction fatal accidents using a standard of four-level classification based on the science of human factors analysis; Sawacha, Naoum, and Fong (1999) analyzed the impacts of the historical, economical, psychological, technical, procedural, organizational and the environmental issues to the construction safety; Behm (2005) linked the construction injuries to the design for construction safety or prevention through design concept. As well, several other studies emphasizing the electrical injury in terms of medicine and health (Cawley & Homce, 2008; Taylor, Jr., Valent, & III, 2002) did not concentrate on the U.S. construction industry. However, a gap of accident analysis on the combined area of the electrical fatality in construction still to some extent exists.

The present study follows prior research but with an attempt to fill the gaps. The objective of the study is, through an examination of electrical fatality investigations, to explore the features of electrical fatalities in construction and disclose the most common safety challenges on construction sites. Further, accident investigations include more hidden information that could be retrieved rather than mere statistical numbers, which this work collects and analyzes as well. Although not funded directly, the objective of this study supports the National Occupational Research Agenda (NORA Construction Sector Council, 2008), in which electrical hazards serve as the number two focus area within the construction sector.

DATA PREPARATION

The electrical fatality data source in this research is the Fatality Assessment and Control Evaluation (FACE) program which is compiled by the National Institute of Occupational Safety and Health (NIOSH 2010). The FACE program provides full text of hundreds of fatality investigation reports since 1982, allowing of the identification of contributing factors to fatal injuries as well as the comprehensive recommendations for preventing similar deaths. The reasons for choosing FACE as data source of this study are: (1) it provides more explicit narratives, detailed contexts and professional investigations compared to only statistical numbers; (2) it is a key occupational safety and health surveillance resource for construction which is recommended by the NORA; (3) learning from failures is believed to be an effective path to success as fatalities are the most serious system failures (Beavers, Moore, & Schriver, 2009; Chi, Yang, & Chen, 2009; Health and Safety Executive 1988); and (4) its representativeness was validated through a pre-conducted T test on victim's age, gender and occupation between the datasets from FACE and the Census of Fatal Occupational Injuries (CFOI).

FACE investigations are composed of two divisions: the NIOSH FACE which is conducted by NIOSH and the State FACE which is conducted by NIOSH's cooperative state partners (for example, the Massachusetts FACE is known to be an exemplary program). Both divisions use the same FACE model. The NIOSH FACE began in 1982 and targeted traumatic occupational fatalities resulting from the death causes of confined spaces, electrocution, machine-related, falls from elevation and motor vehicles. The State FACE began in 1989 and investigated fatal accidents of both NIOSH-level targets and state-level targets, which included falls, electrocutions, suicides and homicides, transportation fatalities, worker deaths involving toxicological issues and chemical-related fatalities. With the exception of author, these two divisions are neither different in format nor overlapped in content.

The scope of data collection was confined to the FACE investigations with the cause of electrocution in construction from 1989 through 2010. FACE reports can be indexed by industry, fatality cause or populations. Construction is one category that could be indexed by industry and Electrocution is another category indexed by fatality cause. Reports under the category of Construction are cases of which the victims belong to the construction industry. As well, the category of Electrocution is the collection of different types of electric shocks and electrocution accidents that occurred. Therefore the overlapped cases under category Construction and category Electrocution from both NOISH FACE reports and State FACE reports were consequently targeted as research objects, since they were eligible to present the research scope of construction electrocution. In addition, electrical deaths occurring in 2010 were the most updated cases used in this study as of December 2012.

The data preparation was manually conducted on the 897 construction fatality investigations which were public assessable from the FACE program website (NIOSH 2010). Since FACE reports did not have a combined category for electrocutions in construction, three basic filtering criteria were applied: (1) the victim died at work; (2) the cause of death was electrocution; and (3) the employer of victim belonged to the construction industry. The definition of being caused by electrocution was according to the decedent's death certificate. The definition of construction complied with the 2010 North American Industry Classification System (NAICS) in which the construction industry was defined between code 230000 and 238990 (US Census Bureau, 2012). In this way, a total of 132 qualified FACE reports with 140 fatalities were selected for following analysis (some accidents resulted in multiple victims).

METHODS

Factor framework

A factor framework of 15 factors was established for content analysis and information organizing. The framework was created and refined through literature reviews and expert consultations. At the beginning, an initial version of the factor framework was developed using a fishbone diagram to cover the fatality time, entities, circumstances, media and causes, all of which can fully imply the fatality features in terms of "when", "who", "what", "how" and "why". According to the data accessibility and research objectives, after several iterations, the finalized factor framework was shown in Table A-3. The factor categorization was determined with reference to existing classifications and industry regulations, such as NAICS, the Standard Occupation Classification (SOC) and the International Electrotechnical Commission (IEC) standards.

Table A-3. Factors framework

No.	Factor Name	Elements
F1	Month	From January to December
F2	Weekday	From Monday to Sunday

F3	Employer's Industry [a]	• Residential BC (2361) • Nonresidential BC (2362) • Utility System Construction(2371) • Land Subdivision (2372) • Highway, Street, and Bridge Construction (2373) • Other Heavy and Civil Engineering Construction (2379) • Foundation, Structure, and Building Exterior Contractors (2381) • Building Equipment Contractors (2382) • Building Finishing Contractors (2383) • Other Specialty Trade Contractors (2389)
F4	If the employer has a written safety policy?	• Yes • No
F5	If the employer provides a safety training program?	• Yes • No
F6	Victim's occupation [b]	• Electricians (47-2110) • Line installers and Repairers(49-9050) • Supervisors (47-1010) • Carpenters (47-2030) • Cement Masons, Concrete Finishers, and Terrazzo Workers(47-2050) • Construction Labors (47-2060) • Construction Equipment Operators (47-2070) • Pipe layers, Plumbers, Pipefitters, and Steamfitters (47-2150) • Roofers (47-2180) • Structural Iron and Steel Workers (47-2220) • Painters and Paperhangers (47-2140) • Insulation Workers (47-2130)
F7	Victim's age [c]	• 16-19 • 20-24 • 25-34 • 35-44 • 45-54 • 55-64 • 65+
F8	Victim's gender	• Male • Female
F9	Agent(s) that victim touched	• Direct contact with electrical wire • Dump truck, boomed crane or other mechanical equipment • Pipes, poles, or other conductive objects • Energized ladders, scaffolds, or other support equipment • Antenna, arrestors, gates, or other building parts

F10	Physical Work Environment	• Exposed • Unexposed
F11	Project Type	• Residential Building Construction • Nonresidential Building Construction • Heavy and Civil Construction
F12	Voltage Level (Volts)[d]	• Below 1000, • 1,000-15,999 • 16,000-34,999 • 35,000 and above
F13	Electricity Origin [e]	• Power lines (both of overhead and underground) • Transformers, conductors, panels or other electrical components • Powered machinery, tools, appliances, equipment or light fixture.
F14	Human Error Origin	• Victim self • Third person
F15	NIOSH prevention recommendations	See Table A-4.

Notes: (a). F3 elements were classified based on NAICS 2012 and numbers in the parentheses refer to NAICS codes. (b). F6 elements were classified based on SOC 2010 and numbers in the parentheses refer to SOC codes. (c). F7 elements were classified based on the NIOSH age classification. (d). F12 elements were classified based on the IEC standard 60038. (e). F13 elements were classified based on the CFOI electrical source classification.

Previous research supports the use of iterative processes to establish a final set of relative factors. Ling, Liu, and Woo (2009) chose factors F1, F2, F6, F7 and F8 as factors in their research on construction fatalities in Singapore. Beavers et al. (2009) identified factors F3, F4, F5 and F13 while investigating steel erection fatalities in the construction industry. Hinze, Pedersen, and Fredley (1998) established factors F1, F2, F3, F7, F8 and F10 for the analysis on root causation of construction injuries. Huang and Hinze (2003) examined factors F1, F2, F6, F7, F8, F9 and F10 in their study on fall accident analysis of construction workers. Janicak (2008) analyzed factors F6, F7, and F13 in his research on occupational fatalities due to electrocutions. Chi et al. (2009) selected F7, F8, F11 and F13 as factors to determine the cause of electric shock in the construction industry. Mullins (2005) utilized factors F1, F4, F5, F7, F8 to evaluate safety climate deficiencies in construction fatalities.

Content analysis and information extraction

As part of the review process for cases, the research team analyzed information, retrieved from the FACE content, which might not be obvious, but could be important as a factor.

Two specific methods of text analysis were used in this process: (1) using text patterns or key words that match such regular expressions to identify small or large-scale structure e.g. "safety training program"; and (2) using text analytics to attempt to understand the text and link it to other information. Taking FACE investigating report #10MA019 (Massachusetts FACE, 2011) for example, the accident time from text that "August 3, 2010" in this case was captured and categorized into factors F1 (August) and F2 (Workdays); the victim's demographic information from text that"23-year-old male roofer" was captured and stored into factors F6 (Roofers), F7 (Age 16-24) and F8 (Male).

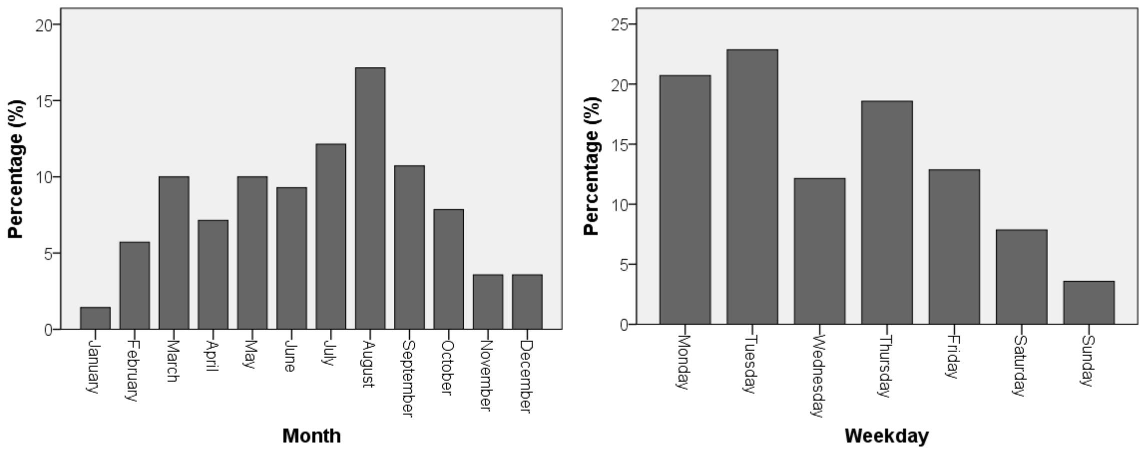
Exploratory analysis

An Exploratory Data Analysis (EDA) technique was chosen for data analysis in this study. Different from conventional statistics, inductive reasoning begins with specific observations and measures, then detects patterns and regularities, and finally ends up developing some general conclusions or theories. EDA is advantageous as it does not rely on preconceived notions on fatal accidents (Ling et al., 2009). Specifically, frequency analysis and chi-squared test were conducted to elaborately describe and interpret extracted and categorized information from electrical fatality investigations. It is important to note that frequencies presented in this research do not necessarily reflect the risk level to workers, but rather describe the problem's proportional magnitude. The team used IBM SPSS V20.0 as the technical software tool to generate analysis results.

RESULTS: FEATURES OF CONSTRUCTION ELECTROCUTIONS

Time of electrocution occurrence

Based on data analysis, the frequencies of electrical fatality incidents occurring by month and weekday are presented in Figure A-1. The number of electrical deaths in construction peaked in August at 17.1% and bottomed in January at 1.4% of the entire electrocutions. Summer was the season with the most electrical accidents (39.3%) while winter contained the fewest (10.7%). Also, 122 electrical fatalities (87.1%) occurred during workdays and most of them were at the beginning of the week, on Monday (20.7%) and Tuesday (22.9%).



(a) F1: month of electrocution occurrence (b) F2: weekday of electrocution occurrence

Figure A-1. Electrocution distributions by occurrence timing.

Summer has the most favorable weather conditions for outside activities and August has the highest average temperature in North America. Based on findings, hot weather conditions could contribute to lower awareness of potential electric hazards for workers, especially when conducting tasks in an open area. On the other hand, the high volume of construction fatalities might simply be a result of the high concentration of projects in warm areas and during warm seasons. Combining features of work and the rate of work together may also contribute to effects that increase the number of accidents in summer for certain types of work.

Employers of electrocution victims

Information about victims' employers is presented in Table A-4, in which 28.6% of electrical deaths were associated with building equipment contractors categorized as "Specialty Trade Contractors". These contractors install and operate specialized building equipment, such as cranes, boomed vehicles, elevators, escalators, service station equipment and central vacuum cleaning systems. Work scopes may include new work, additions, alterations, maintenance and repairs. Also, Special Trade Contractors contain the highest percentage of electrical fatality at 46.4% while the category of "Building Constructors" (BC) represents the lowest percentage at 18.4%.

Table A-4. Electrocution distributions by victim's employer

F3: Employer/Industry	N	Pct. (%)
Building Constructions (BC)	26	18.6
Residential BC	14	10.0
Nonresidential BC	12	8.6
Heavy and Civil Engineering Construction	49	35.0
Utility System Construction	35	25.0
Land Subdivision	1	0.7
Highway, Street, and Bridge Construction	7	5.0
Other Heavy and Civil Engineering Construction	6	4.3
Specialty Trade Contractors	65	46.4
Foundation, Structure, and Building Exterior Contractors	10	7.1
Building Equipment Contractors	40	28.6
Building Finishing Contractors	6	4.3
Other Specialty Trade Contractors	9	6.4
Total:	140	100.0

Note: Rounding off error may occur in calculating percentage.

Figure A-2 shows that more than 50% of employers neither had a written safety policy nor provided a safety training program, according to the statements in FACE investigations. This finding is surprising, as standards of the Occupational Safety and Health Administration (OSHA) explicitly require the employer to train employees in the safety and health aspects of their jobs. Hence, a lack of safety policy and training programs could affect the likelihood of electrical injuries to construction workers.

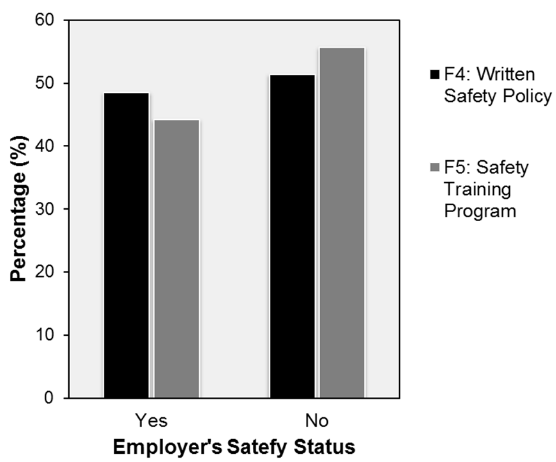
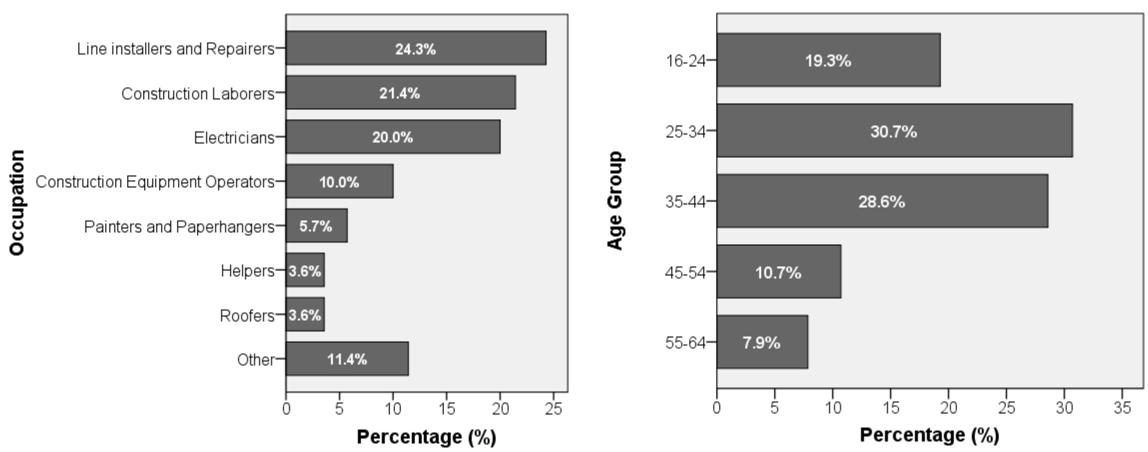


Figure A-2. Electrocution distributions by employer's safety status.

Victim's demographic characteristics

Figure A-3a shows the 7 occupations with the highest number of electrical fatalities. Line installers and repairers (24.3%) and electricians (20.0%) account for the first and third largest portions of electrical deaths, although they typically received extensive training in the electrical safety and the hazards associated with electrical energy. Moreover, construction laborers (21.4%), who generally receive little or no electrical training, rank the second highest occupation for electrocutions. Ten percent of victims are construction equipment operators such as construction crane operators, dump truck drivers and boom mounted vehicles operators. All the occupations contributing less than 3%, merged into the category of "Others", include plumbers (2.9%), carpenters (2.1%), structure steel workers (1.4%) and cement masons (1.4%). Of the 12 various occupations involved in construction electrical accidents, the top five occupations cumulatively represent 81.4% of the total electrical fatalities. Rather than line installers/repairers and electricians, non-electrical occupations, who generally encounter few electric sources in their regular work, account for 55.7% of total electrical fatalities.



(a) F6: by victim's occupation (b) F7: by victim's age

Figure A-3. Electrocution distributions by victim's occupation and age group.

Note: missing data may cause the accumulated percentage less than 100% shown above.

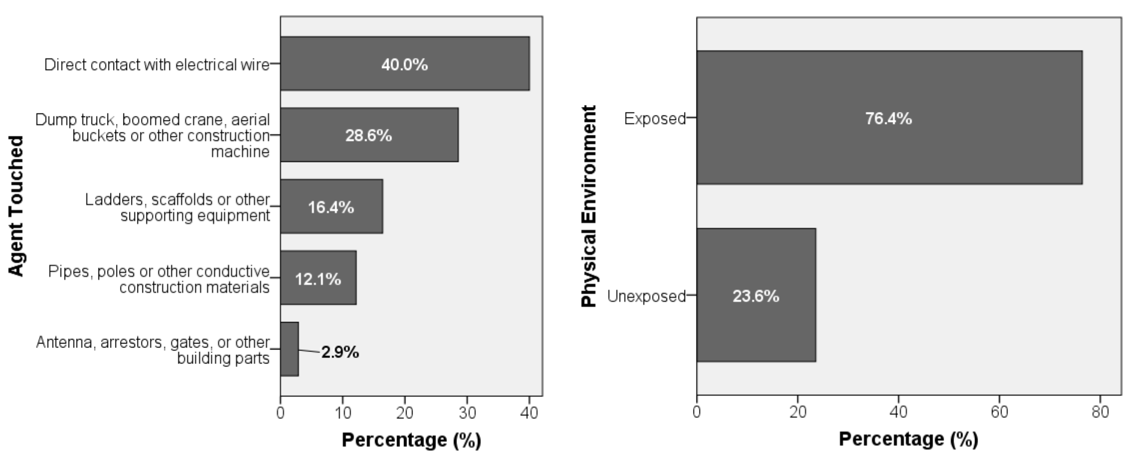
Victims' ages range from 16 to 61 years old with the mean of 35.2 years. Among all victims, there is only one under 18, a 16-year-old electrical-contractor laborer who was electrocuted in 1996 due to energized power lines. As shown in Figure A-3b, victims in age group of

25-34 dominate the electrical fatalities at 30.71%, followed by the group of 35-44 at 28.57%. Young victims dying prior to age 55 are substantial, accounting for over 90%. For the premature fatalities due to electrocution in this research, the years of potential life lost (YPLL) before age 65 equaled 4,021 years (Gardner & Sanborn, 1990).

Pertaining to the victim's gender, data from factor F8 (gender) indicated 100% of them were male, the dominant gender of the industry.

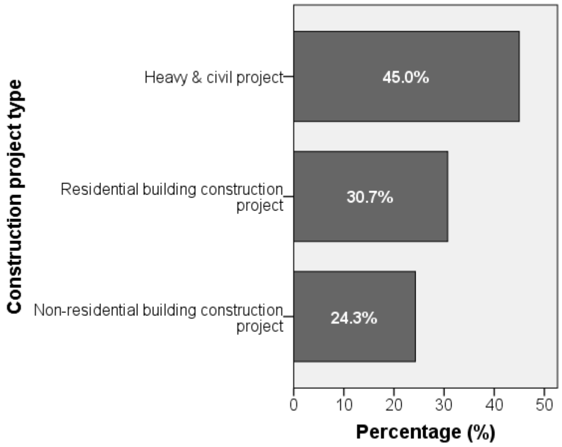
Circumstances of electrical accidents

As shown in Figure A-4a, live electrical wires are the agent of 40% of electrocution victims, who directly touched them in some way. Electrical wires include overhead power lines and underground power lines. Construction machines such as dump trucks, boomed cranes and aerial buckets are the agents that the second most victims were touching, accounting for 28.6%. Interestingly in these data is that the substitution of aerial buckets for ladders as a safety control does not seem to eliminate the risk of electrocution. The data also indicate that supporting equipment such as aluminum ladders or scaffolds and construction materials such as pipes rank as the third and fourth riskiest agents in being electrocuted, respectively accounting for 16.4% and 12.1% of electrical deaths.

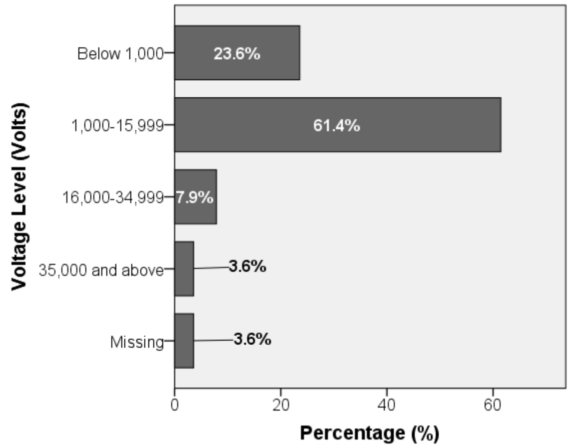


(a) F9: by agent that victim touching

(b) F10: by physical environment



(c) F11: by construction project type



(d) F12: by voltage level (volts)

Figure A-4. Electrocution distributions by electrocution circumstances.

Note: missing data may cause the accumulated percentage less than 100% shown above.

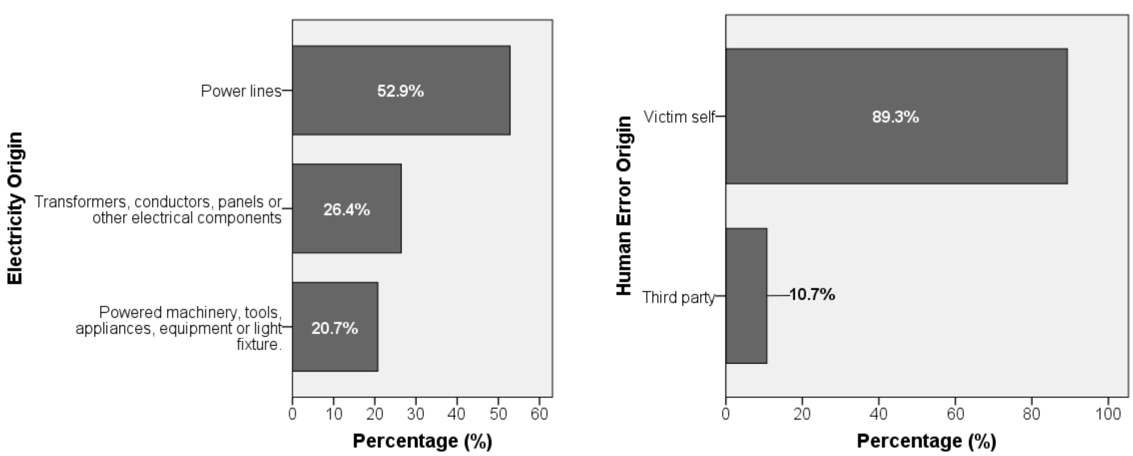
Figure A-4b indicates that over three quarters (76.4%) of electrical fatal accidents occurred in exposed construction sites. Such outdoor working environments might be impacted by natural conditions such as weather, sunshine, temperature and humidity (similar to findings of "timing" above). The minimum clearances of live electrical source also differ between outdoor and indoor working environments since the outdoor clearance is usually longer than the indoor (National Fire and Protection Association, 2008).

Regarding the occurrence of construction incidents by type of work (see Figure A-4c), heavy civil projects possess the largest portion of fatalities (45.0%), which was followed by residential building projects (30.7%) and non-residential building projects (24.3%). The most frequent heavy civil projects that involve incidents are power transmission, distribution substation, road, bridge and gas station constructions. Residential building projects include the construction and repair of houses, apartments and condominiums. No-residential building projects involve manufacturing facility, warehouse, shopping mall, store, school, commercial office and recreation facilities.

As shown in Figure A-4d, 61.4% of electrical fatalities in construction involve the alternating current (AC) of 1,000-15,999 volts. The voltages within this range, such as standard voltage of 4,160V, 7,200V, 12,470V, 13,200V or 14,470V, are usually used for the local power distribution. Specifically, voltage of 7,200V dominates for 23.6% of all electrocutions and 23.6% of electrical accidents which involved low voltages are less than 1,000V (International Electrotechnical Commission, 2002; National Fire and Protection Association, 2008; Reese & Eidson, 2006). The combined voltage level for long-distance distribution (16,000-34,999 volts) and transmission (35,000 volts and above) approximately account for 11% of all electrical fatalities.

Origins of electrical accidents

The research team also examined the origins of the electrical fatality, with human error as a possible origin. As shown in Figure A-5, 52.9% of the electrical fatalities in construction derive from energized power lines and 89.3% of those fatalities result from the victim's improper operation or insufficient hazard awareness. These data suggest that power lines, especially overhead ones, are the primary electrical hazard in U.S. construction. It is important to note that 10.7% of electrical deaths were related to the conduct of a third person, where the victim was not necessarily at fault.



(a) F9: by electricity origin (b) F10: by human error origin

Figure A-5. Electrocution distributions by origin.

Prevention controls

FACE investigators provided several recommendations at the end of each report. These recommendations targeted incident causes and system defects, and thus could be used for injury control and safety promotion. Each listed recommendation might not be stated exactly in a similar way, but the meaning of each one can be generalized (Kunadharaju, Smith, & DeJoy, 2011). In this regard, the team read every recommendation from every FACE report and examined and categorized these statements as well.

The results (see Table A-5) show that within the examined 132 electrocution reports, 62.9% incidents (n=83) suggest a need to provide adequate and effective safety training on electrical hazard identification and prevention. Providing appropriate equipment and conducting jobsite hazard surveys tie for the second most recommendations at 47.7%. This content suggests that the enhancement of electrical hazard awareness can be critical for construction workers to avoid being electrocuted and that the training is an axiomatic part of injury prevention strategy.

Table A-5. Top-ranked NIOSH recommendations

NIOSH Recommendation	N	Pct. (%)
Adequate safety training and periodic specialized electrical safety training programs should be implemented to enhance the electrical hazard cognition and the avoidance of unsafe conditions in workplace.	83	62.9
Well-designed non-conductive personal protective equipment (PPE), communication equipment and supporting equipment should be provided and enforced to workers in workplace.	63	47.7
An electrical hazard survey should be conducted at jobsite to identify potential electrical hazards and intervention measures before work.	63	47.7
Compliance with safety procedures that required by existing federal and state standards and regulations should be ensured, such as the proper grounding, minimum clearance and lock-out/tag-out procedures.	56	42.4
Power lines should be de-energized or insulated before all works start.	45	34.1
On-site safety procedures, safety meeting and safety inspection should be enforced at construction site on a routine base.	44	33.3
Electrical safety procedures and preventions should be thoroughly considered and improved at the construction planning stage.	23	17.4
Guarding co-workers, warning signs and the supervisory guidance should be ensured on site.	18	13.6

To further explore the impact of safety training to other electrocution features, the team conducted Chi-squared tests between F5 (safety training) and each of the other factors. Results statistically support the differences between F5 and F1 month (p=23.124, significance=0.017); F5 and F3 employer (p= 0.251, significance=0.012); F5 and F4 safety policy (p=0.601, significance$<$0.001); F5 and F7 age group (p=0.267, significance=0.045); and F5 and F11 project type (p=18.321, significance$<$0.001). Differences between F5 and each of the rest factors (F2, F8, F9, F10, F12, F13 and F14) could not be supported. As suggested in the FACE investigator statements, safety training (F5) is a critical part of the industry that must be considered by employers, age groups, project types and be part of the written training policy.

CONCLUSIONS AND DISCUSSION

Electrocution is among the “fatal four” in U.S. construction, according to the Occupational Safety and Health Administration (OSHA). Learning from failures is believed to be an effective path to success, with fatalities being the most serious system failures. As a result, this paper explored failures in electrical safety by analyzing all electrical fatality investigations from the Fatality Assessment and Control Evaluation (FACE) program completed by the National Institute of Occupational Safety and Health (NIOSH). A total of 132 FACE investigations with 140 victims from 1989 to 2010 were selected and examined. The data are partially representative, which is supported by the pre-conducted T test on victim’s age, gender and occupation between the datasets from FACE and the Census of Fatal Occupational Injuries (CFOI). Nevertheless, possible statistical limitation ascribed from the limited number of FACE cases remains.

Results reveal the typical features of the electrical fatalities in construction and disclose the most common electrical safety challenges on construction sites. Extra care with electrical hazards should be taken when working in hot weather timing since electrical fatalities were significantly dense in summer, especially in August. Both exposed working environments in construction and relatively high frequency of construction projects during this season pose another explanation. Firms such as construction equipment contractors, utility construction contractors and residential builders are commonly involved in electrical accidents and should pay particular attention to electrocution prevention efforts for their employees, at a minimum the OSHA required. Occupations particularly susceptible to electrocution include line installer and repairer, construction laborer, electrician and construction machine operator. Data suggest that young male workers within the age 25 to 44 bear higher risk of getting electrically shocked. Such age data might also include young construction workers (within the lower part of this age range) that are less matured in hazards awareness and lack safe practical experiences, which could be a topic of future research. Outdoor tasks involving power lines, boomed vehicles and supporting equipment such as ladders and scaffolds are exposed to a relatively higher electrical risk and thus require additional safety training and possible countermeasures. More than half of construction electrocutions originated from power lines for local distribution systems with voltage ranging from 1 kV (1kV=1,000 volts) to 16 kV, which are worthy of special attention in terms of hazard surveys and safety inspections.

Of interest, when comparing these electrical fatality findings with census statistics (e.g., CFOI), a similarity of occurrence time, victim's demographic characters exists and is methodologically supported. Current findings on fatality entities, accident circumstances and electrocution origins also supplement missing data from other previous studies. As a result of consistency across data types and a lack of coverage, the reported electrocution features and safety challenges can also be used as a basis to initiate further thinking on the fatality mechanisms and preventions for the larger construction industry.

Outside of the statistical findings, sociotechnical system breakdowns seem to provide an essential contribution to electrocution occurrence. Haslam et al. (2005) supported this concept with findings in which worker actions and behaviors, as an involving factor, determines 49% of construction accidents. Coupled with NIOSH prevention recommendations, findings suggest that these sociotechnical system breakdowns are commonly associated with a failure to identify electrical hazards involved in completing a task or the incorrect use of equipment (Strauch, 2002). Errors can result from the lack of knowledge, task inexperience and deficiencies in training (Hasan & Jha, 2012; Read, Lenné, & Moss, 2012), which also confirms NIOSH's top recommendation of implementing effective safety training for electrical hazard cognition and unsafe condition avoidance in the workplace. It is especially important for hazard awareness training to be a major goal in reducing electrical accidents (Zhao, Lucas, & Thabet, 2009). The author suggest such breakdowns to often be system-based rather than only worker error (Kleiner, Smith-Jackson, Mills, O'Brien, & Haro, 2008).

From a hierarchy of controls design perspective, risk should be designed out of features of work, with administrative controls such as training and personal protective equipment (PPE) as mandatory measures, whose reduction of risk is a final layer of protection and not a protection strategy necessarily. Trained victims account for approximately half of the victims in this study, which implies that basic accident prevention might not be enough if other factors such as project hazard level and safety culture level present a high risk (Feng, 2013). Also, the chi-squared tests here cannot statistically validate differences between trained cases and untrained cases for many factors, suggesting that the effectiveness of current safety training programs for electrical safety in construction might be inadequate and could have the ability to decrease unsafe behavior and mitigate differing types of accidents. Further, as concluded by Huang and Hinze (2003), traditional safety training may not be sufficient to enable construction workers to detect and eliminate the broad array of potential hazards, and therefore innovative training approaches should be considered.

This study proposes challenges of electrical safety in construction, but several limitations exist and some areas need to be addressed in future research. One limitation is due to the relatively small data size of FACE investigations. To minimize any possible bias, which may be caused by this limitation, a T-test was conducted whose results supported an avoidance of this bias. Moreover, data from fatality reports are strong in a comprehensive context, which includes more information than census statistics. Another limitation is the possibility of subjective opinions from investigators. The team therefore used precautions for mitigating this limitation when designing the factor framework. To a great extent, more objective factors were chosen for analysis. For future studies, particular concerns on safety training and hazard design-for-safety may need to be further investigated to address significant fatality controls.

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APPENDIX B

FACE INVESTIGTION SUMMARIES

FACE ID	Summary
1989-26	On March 6, 1989, a 21-year-old male apprentice lineman was electrocuted when he contacted a 13,700-volt power line while upgrading a power distribution system.
1989-27	On January 20, 1989, a 37-year-old male distribution line technician received third-degree burns to his leg and back when he contacted an energized conductor while repositioning a bucket to perform maintenance on a power line. He died 37 days later as a result of a secondary infection.
1989-36	On April 20, 1989, a 44-year-old male distribution line technician was electrocuted and a second distribution line technician received severe electrical burns when a new conductor they were installing contacted an existing, energized 7200-volt power line.
1989-37	On June 1, 1989, a 21-year-old male laborer was electrocuted when his hand contacted a 4160-volt power service line.
1989-39	On May 2, 1989, a 20-year-old male apprentice lineman died after making direct contact with a 7200-volt primary wire.
1989-40	On May 13, 1989, a 40-year-old male service operations technician died after contacting an energized 7680-volt switch while observing a service operations technician trainee operating the switch.
1989-42	On June 21, 1989, a 24-year-old male television (TV) cable installer was electrocuted when he came in contact with a 7280-volt powerline running 5 feet above the roof of a house.
1989-48	On August 22, 1989 a 43-year-old male truck driver died when the boom of the truck mounted crane he was operating contacted a 14,400-volt overhead powerline.
1989-50	On August 23, 1989, a 23-year-old male apprentice electrician was electrocuted while making a connection for a light fixture in a junction box.
1990-01	Three construction workers were electrocuted, and three others wore seriously burned, when the mobile elevating work platform they were moving contacted the bottom phase of a 69,000-volt overhead powerline. This occurred as the crew was installing aluminum siding to one side of a 25-foot warehouse under construction. The three-phase powerline, which ran parallel to the warehouse, is 7-feet lower on the north end of the warehouse than on the south end. On the south end, the powerlines were attached to the horizontal crossarm of a utility pole so that all three phases were 34 feet off the ground. The powerlines twist 90 degrees from the horizontal orientation to a vertical orientation, and were attached directly to the utility pole on the north end of the warehouse, where the bottom phase is only about 27 feet off the ground. The six crew members were working from the south end of the warehouse, where adequate clearance for the 25 foot 6 inch platform existed, toward the north end. They moved the platform under the lowest part of the powerline at a point where the ground sloped upward to meet the existing roadway. The platform's top guardrail contacted the bottom phase of the powerline, and current passed to ground through the platform and the workers who were touching it.

1990-03	A line crew, assigned the task of restoring power to secondary service lines at night, determined that a switch had to be opened on a pole-mounted transformer to de-energize the line on which repairs were to be made. The powerline repairs were needed as a result of damage caused by Hurricane Hugo. A co-worker lifted a hot stick to open the switch. As the victim walked toward the co-worker, his right arm contacted a powerline that was dangling from the pole. He fell backward and landed on his back on top of the powerline. The dangling phase was aluminum, while all other phases attached to the pole were copper. A guy wire anchor was buried in the ground approximately 20 feet from the pole, but no guy wire was attached. It is assumed that the victim either did not see the wire because of the darkness or thought that it was a guy wire (because of its color) and believed, therefore, that it was not energized.
1990-04	A power company crew (a supervisor, a lineman, and two meter readers) was assigned the task of restoring secondary service to residences in an area that had been damaged by Hurricane Hugo. When the crew arrived at the jobsite after dark, the supervisor decided that two phases of an existing three-phase drop service needed to be reattached to a pole-mounted transformer near a residence. When the lineman had completed reattaching the two phases, one of the meter readers (the victim) went to the residence to tell the occupants that their power had been restored. As the victim stepped over a chain-link fence into the yard of the residence, he lost his balance and grabbed a wire clothesline in an effort to regain his balance. Co-workers noticed the victim was being shocked and knocked him away from the clothesline and fence. The wire clothesline was attached to a metal pole that supported the tin roof of the residence. An energized secondary service from a nearby residence had been torn loose from its connection and was lying across and energizing the tin roof, metal pole and clothesline at 110 volts. When the victim grabbed the wire clothesline, his body provided a path to ground, causing his electrocution.
1990-05	A construction crew consisting of a supervisor, three class A linemen (including the victim), a first class lineman, a groundman, and two truck drivers were assigned the task of correcting a malfunction in a de-energized three-phase powerline. When the crew arrived at the worksite, they found that one of the three phases had broken and fallen to the ground. The supervisor instructed the victim to relocate the damaged phase on the crossarm of the pole to better balance the load on the crossarm. As the victim began to climb the pole he was assured by the supervisor that the powerlines had been de-energized. When he attempted to relocate the damaged line he contacted another phase, was shocked, and slumped backwards, prevented from falling by his safety belt. The powerlines at the worksite had been energized by backfeed electrical energy from a portable gas generator being used on the circuit.
1990-06	A journeyman lineman working to restore electrical power in the wake of Hurricane Hugo was electrocuted when the boom and bucket of the bucket truck in which he was working rotated into an energized 4800-volt powerline. Just prior to the incident, the lineman noticed that a plastic tool basket, mounted on the side of the bucket with copper-wire hooks, was full of water. He removed the basket from the side of the bucket, and emptied it. When the lineman attempted to reinstall the tool basket in the dark, one of the hooks caught on the lever which controlled boom rotation, and engaged it, causing the boom to swing into the powerline. The victim's body made contact with an energized 4800-volt powerline and a secondary fuse box. The jolt of the bucket striking the lines caused the victim to be thrown from the bucket to the ground 30 feet below.

1990-08	A utility company line technician was electrocuted while working to restore electrical service that had been interrupted by Hurricane Hugo. The victim and a co-worker had been clearing debris from a pole-mounted three-phase 7200-volt powerline. When they thought the line was clear of debris, the victim asked substation workers to energize the three phases. However, the recloser (an automatic switch or circuit breaker that reestablishes an electrical circuit after an interruption of service) on the middle phase opened indicating that a problem with that phase still existed. The workers, who started to look for the problem without requesting that the powerlines be de-energized, found that the middle phase had been pulled down into a guy wire by storm debris. The victim climbed the pole to cut the middle phase, and called to his co-worker to throw him a pair of pliers. The co-worker asked the victim whether he wanted his hardhat tossed up as well, but the victim declined. While he was maneuvering between the powerlines, with his feet on the neutral wire, the back of the victim's head contacted an energized jumper wire and he was electrocuted.
1990-09	A painter was electrocuted and his co-worker injured, when a portable aluminum extension ladder contacted a 7,200-volt powerline. This incident occurred as the two workers were painting a two-story aluminum-sided house. The powerline was located parallel to, and approximately 10 feet from, one side of the house. The powerline was 22 feet off the ground. The victim was using a 30-foot aluminum extension ladder to paint the upper part of the house, while his co-worker was using a stepladder to paint the window trim on the first floor. The victim had progressed to a point where repositioning the ladder was necessary to continue painting. He descended the ladder, placed the paint brush and bucket on the ground, and proceeded to move the ladder. The ladder tipped backwards and contacted the powerline. The current passed through the ladder and victim to ground while he was still in contact with the energized ladder.
1990-10	A carpenter was electrocuted when a strip of aluminum drip edging he was installing contacted a 7,200-volt powerline located behind and above him. The victim was working on replacing the roofing on a 45-year-old house. The powerlines were located 6 feet away from the house and 5 feet above the edge of the roof. The victim was working from an aluminum ladder jack scaffold when a segment of edging he was apparently placing in position contacted the powerline, allowing the current to pass through his body to ground.
1990-26	A lineman was electrocuted when he contacted a 7,200-volt cutout switch on a newly installed utility pole. Just prior to the incident the victim had climbed the utility pole, installed a cutout switch, and connected it (with a jumper cable) to a 7200-volt conductor that had not yet been energized. He was wearing lineman gloves and a body safety belt with a lanyard. The victim then climbed down the pole, removed his lineman gloves and disconnected his safety belt, and radioed other crew members to energize the distribution line. He was about to close the cutout switch with a hot stick when he noticed a piece of electrical tape hanging from the energized side of the cutout switch. In an attempt to remove the electrical tape, the victim climbed back up the pole (without first putting his lineman gloves and safety belt back on), grabbed a guy wire with his right hand to stabilize himself, and reached with his left hand to remove the tape. In doing so, the victim's climbing boots slipped, causing his left hand to contact the energized side of the cutout switch, and the victim was electrocuted.

1990-27	A 30-year-old journeyman lineman (victim) was electrocuted when he contacted a 7200-volt powerline while installing a guy wire. The victim was a member of a crew that was installing a new single-phase 7200-volt powerline parallel to, and 24 inches away from, an existing energized single-phase 7200-volt powerline. The new utility poles had been set and the crew had begun to string the new powerline. The lineman had previously insulated the existing powerline by placing a 36-inch-long protective line hose over the powerline on each side of the utility pole. On the day of the incident, the victim was instructed by the supervisor to place more line hoses on the existing powerline, to attach a guy wire to an anchor on the new utility pole, and to put the drag rope for the new powerline through a roller at the top of the new pole. The victim told the supervisor that he would further insulate the existing powerline after he installed the guy wire. The victim entered an insulated aerial bucket and was handed the looped end of the guy wire by the supervisor. The victim pulled the guy wire into the bucket and stood on it as he raised the bucket. When the victim reached the guy wire anchor, he took an adjustable wrench from his tool bag and began to loosen the anchor nut closest to the existing powerline. The supervisor was on the ground giving instructions to the groundmen when he heard an arcing sound and looked up to see the victim's right arm in contact with the existing powerline. The victim's clothes caught on fire, and soon afterward the powerline burned in two, breaking contact. Burn marks on the powerline indicated that the victim contacted the powerline 39 inches from the pole, 3 inches beyond the protective line hose.
1990-29	A 29-year-old male laborer was electrocuted when the crane cable suspending a 1-yard cement bucket he was touching contacted a 7200-volt powerline. The victim was a member of a crew that was constructing the back wall of an underground concrete water holding tank at a sewage treatment plant. Before work on the tank was begun, the company safety director, aware of the hazards involved in using a crane near an overhead powerline, requested assistance from the local electrical utility company. As a result, utility company workers placed insulated line hoses over sections of the powerline near the jobsite. The safety director also had markers placed to indicate where arriving cement trucks should stop while the cement bucket was loaded. Loading the bucket at the marked location ensured that the crane boom and cable would remain at least 14 feet from the powerline. (OSHA regulations require that a minimum distance of 10 feet be maintained.) As a result of the precautions taken, the concrete for the wall was poured without incident. However, after the crew had poured the last bucket of concrete to finish the top of the wall, the driver of the cement truck cleaned the loading chute on his truck with a truck-mounted water hose and began to pull away. As he did the crew supervisor yelled to him and asked if the crew could use the water hose to wash out the cement bucket suspended from the crane. The driver stopped the truck under the powerline and the crane operator, not realizing the truck had been moved, swung the boom to position the bucket behind the truck. The victim grasped the handle of the bucket's door and pushed down to open it, bringing the crane cable into contact with the powerline. The electrical current traveled down the cable and through the bucket and victim to ground, causing the victim's electrocution.

1990-31	A laborer died 15 days after a 10.5-foot-long galvanized pipe he was carrying contacted an energized 12,500-volt jumper wire at an electrical distribution system substation. One end of the jumper wire, was attached to a step-down transformer at a position approximately 11 feet above ground level. The other end of the jumper wire was attached to an overhead powerline. The victim was part of a two-person crew assigned to pull wire through a newly installed underground conduit. The victim positioned a truck containing reels of wire, a reel rack, and a galvanized pipe that was going to be used as a reel rack spindle, inside the substation approximately 8 feet from a transformer. While his co-worker (the crew leader) was working on a separate task approximately 40 feet away, the victim apparently lifted the pipe from the back of the truck and turned toward the transformer with the pipe in a vertical position. The pipe contacted the jumper wire, and the current passed through the pipe and the victim to ground, injuring the victim.
1990-32	A 24-year-old male electrician was electrocuted when he inadvertently contacted a 2,300-volt, 6.6-amp conductor. The incident occurred while the victim was working inside a manhole splicing a conductor. The victim and a co-worker were part of a six-person crew assigned to install a new lighting system at an airport. The system consisted of three circuits: 1) an energized 2,300-volt, 6.6-amp runway lighting circuit; 2) an energized 700-volt temporary taxiway lighting circuit; and 3) a de-energized taxiway lighting circuit. The victim entered the manhole through a 24-inch-diameter manway opening and descended a metal ladder attached to the inside of the 5-foot-square by 7-foot-deep concrete manhole. The victim removed a pair of insulated side (wire) cutters from his tool belt to prepare the de-energized taxiway lighting conductor for splicing. He cut a size 8 AWG conductor which was hanging over a rung of the metal ladder without determining whether or not the circuit was energized. The conductor, which was part of the energized runway lighting circuit, separated into two pieces. The energized end came in contact with the back of the victim's right hand. Current passed through the victim's right hand and exited his right thigh at the point where it was in contact with the grounded metal ladder.
1990-38	A well driller was electrocuted when a metal pipe that was being hoisted by a truck-mounted crane contacted one phase of a three-phase, 12,000-volt overhead powerline. The victim and a co-worker had been assigned the task of repairing a submersible pump for a water well at a private residence. The two workers began the repair work the day before the incident. The day of the incident they used a truck-mounted crane to pull piping and the submersible pump from the well. The well was located in a pasture that is intersected by three separate and parallel overhead powerlines. A phase from one of the powerlines passes directly over the well, 31 feet, 6 inches above the ground. On the day of the incident, the victim positioned the truck-mounted crane beneath the powerline. Using a hand-held remote control pendant, the victim fully extended the end of the boom 36 feet above the ground. The crane cable was attached to a 1-inch diameter galvanized pipe that ran to the pump inside the well. As the victim raised the pipe it contacted the powerline phase directly above the well. This action energized the crane, including the hand-held remote control pendant. The victim provided a "path to ground" and was electrocuted.

1990-40	A 29-year-old utility lineman was electrocuted when he simultaneously contacted both sides of a fused powerline jumper. One end of the jumper was attached to the powerline, the other was attached to a recently installed pole-mounted transformer. The jumper served as a temporary connection between a powerline phase and a transformer that allowed electrical service to be provided through the transformer. The week before the incident, the victim had moved the outside phases of a three-phase, 2400-volt powerline to temporary insulators at the center of the crossarm at the top of a utility pole. This work was done to ease tree trimming operations around these lines. On the day of the incident, the victim was working from an aerial bucket moving the two outer powerline phases back to their permanent positions at each end of the crossarm. Two workers on the ground were using a hemp rope the victim had tied to the powerline phase to position the powerline on the insulator. When the powerline was in position, the victim told the workers on the ground to hold it in position while he secured tied it to the insulator. One of the co-workers then noticed one of the victim's leather gloves smoking and that the victim was slumped over in the bucket. The truck stalled, preventing the workers on the ground from using the truck-mounted controls to lower the aerial bucket. One of the workers ran to a nearby farmhouse to summon the emergency medical squad (EMS). The second worker notified the company of the incident from the truck radio. After alerting the company, the second worker climbed the pole, de-energized the new transformer, entered the aerial bucket and initiated cardiopulmonary resuscitation (CPR). As the first worker was returning from the farmhouse, a tree trimming crew arrived at the site in another aerial bucket truck. The first worker and a member of the tree trimming crew used the tree trimmers' aerial bucket truck to remove the victim. from his bucket and lower him to the ground. The EMS transported the victim to the hospital where he was pronounced dead by the attending physician. The investigation revealed that one end of a temporary fused jumper was connected to the powerline on which the victim was working. The other end of the jumper was connected to the new pole-mounted transformer. This jumper had been pulled in two. It is assumed that the jumper pulled apart as it was being attached to the insulator. While attempting to prevent the separation the victim contacted both sides of the jumper simultaneously. This action allowed current to pass across the victim's chest and caused his electrocution.
1990NJ006	A two-man crew of electricians was installing new wiring through an existing conduit in a department store ceiling. While using a personnel lift to work overhead, one of the workers made contact with an energized 277 volt electrical circuit. He was electrocuted and fell out of the lift.
1990NJ013	On July 26, 1990, a 28-years-old insulation installer was killed when an aluminum extension ladder which he was holding made contact with an overhead power line, causing him to receive 2,400 volts of electricity. Two experienced insulation installers, both foremen, were raising an aluminum extension ladder in order to start a job. The victim held the ladder while his partner used a rope to extend the ladder.
1990NJ014	On August 28, 1990, a 31-year-old male laborer was killed, apparently as a result of contact with equipment thought to be deenergized. Working at the bottom of a 24-foot deep dry well at a sewer pumping station, the victim backed into the frame of a disconnected heater and apparently received an electric shock of a least 0.53 volts AC, sufficient to have caused an electric shock. Careful monitoring of electrical components in the area revealed ground faults which caused the wall heater frame to be energized.

1990NJ015	On September 7, 1990, an apprentice lineman died after making contact with the secondary power lines on a utility pole. While preparing to replace the old primary wiring on the pole, the lineman was passing nylon rope around two 110 volt secondary lines when he contacted both lines simultaneously with his arms.
1991-05	A 19-year-old male construction laborer (victim) was electrocuted after handling a damaged extension cord that was energized. The victim, a second laborer, and a foreman were constructing a waterfront bulkhead for a residence at the edge of a lake. Electric power was supplied from an exterior 120-volt, grounded AC receptacle located at the back of the residence. On the day of the incident, the victim plugged in a damaged extension cord and laid it out towards the bulkhead. There were no eyewitnesses of the incident. However, evidence suggests that while the victim was handling the damaged and energized extension cord, he provided a "path to ground," and was electrocuted. The victim collapsed into the lake and sank 4½ feet to the bottom.
1991-08	A 62-year-old male truck driver (victim) was electrocuted while touching a dump truck that became energized. The victim had been instructed to pick up and transport a load of gravel to a location in a rural section of the state, where a septic system was being installed. The victim picked up the gravel at a limestone quarry and drove a tractor-trailer dump truck to the incident site to unload it. The victim drove the truck off the paved road onto a grassy field where the drain field for the septic system was located. He then backed the tractor-trailer into a position directly beneath one phase of a 7,200 volt, 3-phase powerline located about 20 feet above ground level. The victim set the air brakes, exited the cab of the truck to engage the lever opening the trailer's tailgate, re-entered the truck cab to engage the power takeoff system, and again exited the truck cab. While standing on the ground, the victim engaged the lever that raised the bed of the truck into inadvertent contact with the powerline phase. Contact between the truck bed and powerline allowed current to flow through the truck to the ground. The victim, who was in contact with the lever on the truck, provided an alternate path to ground for the electrical current and was electrocuted.
1991-10	A 33-year-old lineman (the victim) was electrocuted after contacting a 7600-volt powerline during an attempt to restore electrical power during a storm. A large tree had fallen across a 7600-volt, single-phase powerline, pulling both the primary and neutral conductors to the ground. After arriving at the site, the victim and a co-worker, also a lineman, did not de-energize the powerline. Instead, the victim told the co-worker he would first ground the line at the utility pole immediately up-line from the fallen tree by temporarily splicing a jumper cable between the primary conductor and the neutral conductor. The two linemen would then repair the powerline by splicing together the downed conductors above the fallen tree. To do this work, the victim entered an insulated aerial bucket and raised it to the primary conductor near the utility pole. At the same time, the co-worker cut the downed primary and neutral conductors next to the fallen tree. Although there were no eyewitnesses to the incident, evidence suggests that the victim began working on the energized powerline without first grounding the line. The victim cut the neutral and primary conductors while inside the aerial bucket, and was attempting to attach a chain hoist to the energized end of the primary conductor. Wearing only his leather work gloves, the victim presumably grabbed the supply end of the primary conductor with his right hand. At the same time, the chain hoist that the victim held in his left hand contacted the neutral jumper, thus providing a path to ground through his chest, and he was electrocuted.

1991-21	A 37-year-old construction laborer (victim) was electrocuted while pulling a wire rope load choker attached to a crane cable toward a load. The choker was to be connected to a steel roof joist which was to be lifted 150 feet across the roof of a one-story school and set in place. The cab of the crane was positioned 11 feet 6 inches from a three-phase 7200-volt powerline. After a previous roof joist had been moved, the crane operator swung the crane boom and cable back toward the victim. The victim grasped the choker in his left hand and with his right hand held onto a steel rod that had been driven into the ground nearby. At this point, the crane cable contacted the powerline and the electrical current passed across the victim's chest and through the steel rod to ground, causing his electrocution.
1991-22	A 59-year-old male laborer (victim) was electrocuted while painting a section of support steel for a conveyor system that was being installed at an automotive parts assembly plant under construction. The victim and a co-worker were in separate single-man lifts, "touching-up" the steel with paint brushes. After lowering their lifts to get additional paint, the victim and co-worker discussed getting "minor" shocks from the conveyor. The co-worker assumed it was from nearby welders. Within minutes after the victim and co-worker resumed painting, the co-worker turned and saw the victim slumped in his lift. Once the victim was lowered to the ground by others in the area, co-workers immediately administered cardiopulmonary resuscitation (CPR). The victim was unresponsive. An emergency medical service (EMS) unit arrived within 10 minutes and transported the victim to the local hospital, where he was pronounced dead, 45 minutes after arrival. Co-workers at the scene indicated that shortly after the incident several pieces of equipment and materials were removed from the site.
1991-25	A 27-year-old male electrical lineman (victim) was electrocuted when he contacted an energized trailer-mounted line tensioner. The victim was a member on a crew that was stringing new conductors to replace an existing three-phase, 14,200-volt powerline. The existing energized conductors had been repositioned and attached to insulators on extensions bolted to the power pole crossarms. The crew had been pulling a new conductor through rollers attached to the same crossarm on three consecutive power poles, a span of 300 feet. A 4-foot clearance existed between the new conductor and any of the existing conductors. At the time of the incident, the victim and a co-worker (groundman) had been working at a trailer-mounted line tensioner. The new conductor was being pulled in a straight line from the tensioner by a pulling rig located immediately behind the farthest power pole. Because of either improper tension on the new conductor or a failure of the tensioner's braking system, the conductor began to pull from the tensioner in a jerking motion. This motion caused the conductor strung through the rollers to sway back and forth and contact one of the existing phases. Current traveled back through the conductor, energizing the tensioner and fatally shocking the victim, who was in contact with the tensioner.

1991-29	A 27-year-old crew foreman was electrocuted when he contacted an energized conductor on a utility pole. The foreman was part of a three man crew stringing new television cable in a residential section of the city. Prior to the incident, the foreman attached one end of a polyethylene rope to the cable wire. A weight was attached to the other end of the rope. The rope was then supposed to be thrown over the existing cable wire which was attached between the utility poles. When the rope was thrown, it became tangled in the overhead powerlines above the existing cable wire. The foreman instructed the lineman to retrieve the wire, but the lineman refused to do so. The foreman then donned a pair of linemen's climbers and, without using a safety belt and lineman's strap or lanyard, ascended the utility pole to a position above the transformer, approximately 25 feet above ground level. At this time, the co-workers had their backs turned to the victim when they heard an electrical arcing noise. The victim apparently touched an energized conductor (e.g., jumper wire, fuse, fuse holder, powerline, etc.,) and fell to the ground. In that neither co-worker had CPR training, potentially critical CPR care could not be immediately administered to the victim.
1991-32	A 33-year-old male (victim), employed as a heating, ventilating, air-conditioning, and refrigeration (HVACR) technician, was electrocuted while performing refrigeration maintenance on a walk-in cooler at a restaurant. The flexible metal conduit housing the power conductors to the refrigeration unit (RU) of the cooler had been designed to serve as the mechanical ground. The insulation on one of the three power conductors in the flexible conduit was damaged and allowed electrical arcing to a conduit connector on the RU starter box (Figure). The conduit connection to the RU starter box (from the RU) was loose, and effectively disconnected the mechanical ground from the RU. As the victim was servicing the RU, the temperature in the walk-in cooler must have caused the thermostat to close the starter, energizing the surfaces of the RU, and fatally shocking the technician when he touched it.
1991NJ003	On February 15, 1991, a 53-year-old electrical substation mechanic suffered a fatal fall after making contact with an energized 26,000 volt power line. The incident occurred when the victim climbed a ladder and attempted to free a jammed switching device. Thinking that the lines were de-energized, the worker was shocked after touching a live electrical conductor, causing him to fall 12 feet to the ground.
1991NJ009	On June 17, 1991, a 21-year-old electrician's helper was electrocuted after contacting the exposed 480 volt bus wires that supply power to a movable overhead crane. The incident occurred while the worker was running cables for surveillance cameras at a factory which produces foundry equipment. While a co-worker was passing the coaxial cables over an I-beam supporting the bus wires, the victim contacted the energized wires and was electrocuted,
1991NJ012	On July 30, 1991, a 45-year-old male drill operator and a 58-year-old male shop mechanic were electrocuted when their drill rig boom made contact with a 7,200 volt overhead power line. The incident occurred while the two men were moving a drill rig away from the side of a road where they had been drilling test bores. The workers were apparently moving the raised boom of the rig when it contacted the power line, electrocuting the rig operator. The second worker was simultaneously electrocuted while holding a steel-reinforced air hose attached to the drill rig.
1991NJ013	On August 10, 1991, a 26-year-old male bridge painter died after the steel-reinforced water hose connected to his pressure-washing gun made contact with a 13,000 volt electrical powerline. The victim was working from a suspended work platform approximately 50 feet above the powerline.

1991NJ016	On September 6, 1991, a 47-year-old male power company lineman was electrocuted after making contact with a 7,200 volt power line. The incident occurred while the lineman was working to re-route power from a utility pole to underground lines. As he worked from a bucket truck, he contacted the energized line while holding a grounded metal support.
1991NJ017	On September 24, 1991, a 49 year-old male carpenter was fatally injured after falling 22 feet from an aluminum ladder when a section of aluminum siding he was holding contacted a 110 volt overhead power line. The incident occurred at a two story townhouse while the victim was attempting to install a 12 foot section of j-channel. While moving the section, it contacted the power line, shocking the victim and causing him to fall from the ladder.
1992-01	An electrical line mechanic (the victim) was electrocuted while attempting to attach an energized conductor to a crossarm-mounted insulator. The employer had been contracted by a local electric utility to install new power poles and relocate the existing three-phase, 19,900-volt powerline onto the new poles. On the day of the incident the weather was hot and humid. An electrical line mechanic and his foreman were working from separate aerial buckets fastening the 19,900-volt conductors to insulators on opposite sides of crossarms on the new wooden power poles. When the supervisor had positioned the conductor on the insulator on his side of the crossarm, he looked down the line away from the victim to see if the conductor was clear of tree limbs or other obstructions. The supervisor saw a flash out of the corner of his eye and turned to see current arcing across a crossarm bolt in contact with the victim's chest. The victim's arms were in a raised position, clearly not in contact with the conductor; however, the electric current was visibly arcing across the crossarm bolt from the victim's chest, and arcing sounds could be heard in the vicinity of the victim's arms. Sometimes linemen raise their hands and arms to drain perspiration from their protective gloves. Droplets of moisture were later seen on the conductor, insulator, and crossarm, suggesting that the current may have tracked the perspiration into the victim's glove, up his arm, and across his chest. The current then would have gone to ground through the crossarm bolt and down the wooden power pole, causing his electrocution.
1992-02	A 35-year-old male lineman was electrocuted after he contacted an energized powerline while working from the bucket of an aerial lift truck. The victim was part of a five-man crew assigned to transfer a three-phase, 34,500-volt, overhead powerline system from one utility pole to a taller utility pole. The transfer of the powerlines had been completed, and insulating blankets and line sleeves still covered the powerlines, insulators, and crossarms. While removing the line sleeve from the middle powerline, the victim's rubber glove became caught on an aluminum wire securing the powerline to the insulator. When the victim pulled his arm back, the rubber glove was partially pulled off, and the victim's exposed right wrist contacted the powerline. Electrical current passed through the victim's right arm and exited the body at the left side of the lower abdomen, which had been in contact with the utility pole crossarm, causing his electrocution.

1992-06	A 19-year-old roofing mechanic trainee (victim) was electrocuted after he inadvertently contacted an energized service entrance conductor. At the time of the incident, a crew of six workers, including the victim, was performing various tasks on the roof of a warehouse. The victim, in preparing to apply aluminum flashing around the perimeter of the roof, was kneeling on the corner of the roof, taking measurements along the roof's perimeter. Two electrical service entrances were located on the corner of the roof where the victim was working. When the victim completed his measurements and stood up, he contacted one of the energized electrical service entrance conductors (240-volts phase-to-phase) at his chest area. At the same time, his right forearm contacted the grounding wire for the service entrance which provided a path for the electrical current across the victim's chest through his right forearm to ground. Two co-workers knocked the victim away from the service entrance conductors and, without training, attempted CPR care until the local emergency medical service (EMS) arrived. The victim was pronounced dead at the emergency room of the local hospital approximately 25 minutes after the incident occurred.
1992-12	A 37-year-old male electric utility powerline worker (the victim) was electrocuted while performing maintenance on a 7200-volt overhead powerline. The victim had been assigned by the electric utility to investigate and repair a problem involving intermittent power outages in a rural community. Two weeks before the incident, the victim isolated and replaced what he thought was the outage problem (an arcing electric service line) at a utility pole near a school. On the day of the incident the victim climbed the utility pole to adjust the primary phase jumper cable, which he apparently thought was another probable arcing source. He was not wearing his lineman gloves, or his protective helmet. At the moment of the incident, the victim had his left climbing boot gaff planted in the utility pole, his right climbing boot in contact with the pole guy wire, and his left arm/hand resting on the neutral phase. Thinking (presumably) that the powerline had been de-energized, the victim grabbed the energized primary phase jumper cable with his right hand. In doing so, he provided a path to ground (the electric current entered his right hand, and exited his left arm/hand and right foot), and the victim was electrocuted. The forensic pathologist stated in his report that the victim's judgement was probably impaired by the influence of marijuana which the victim may have used shortly before the incident.
1992-24	A 21-year-old roofer's helper (the victim) was electrocuted, and a co-worker received serious electrical burns at a private residence when the metal ladder platform hoist they were positioning contacted a powerline. Prior to the incident, the victim and five co-workers had been removing old roofing materials from a single-story private residence in preparation for the application of new roofing materials. As new shingles were being applied to one side of the roof, the victim and a co-worker were instructed to set up the ladder platform hoist on the opposite side of the residence. The victim and a co-worker carried the ladder platform hoist around the side of the residence and stood it upright from ground level against the edge of the carport roof. As they positioned the ladder platform hoist, it contacted an overhead powerline, and electrical current passed through the ladder platform hoist and both workers, to ground. The victim was electrocuted and the co-worker was seriously burned.

1992-25	A 46-year-old male electrician (the victim) was electrocuted after he contacted an energized powerline while working from the bucket of an aerial lift truck. The victim was part of a two-man crew assigned to replace 12 fused electrical cutout switches located on utility poles at a housing project. The switches were located on the crossarms of the utility poles between the transformers and the powerline phases. Five switches had been replaced and work was in progress on the sixth switch. The victim, without wearing any personal protective equipment, and without covering the powerlines with insulating blankets or line sleeves, removed one of the bolts securing the switch to the crossarm. In his attempt either to remove the second bolt securing the switch or to reposition the bucket, the victim's left upper arm contacted the powerline. Electrical current traveled through the victim's left shoulder and exited his body through the right forearm which was in contact with the grounded bucket controller, electrocuting the victim.
1992-27	A 21-year-old painter (the victim) was electrocuted when the metal ladder he was moving contacted an overhead powerline. Prior to the incident, the victim and two co-workers had been painting the exterior of a two-story private residence. Work had concluded at 9 p.m., and the workers were cleaning up the jobsite. The victim, for unknown reasons, walked around the side of the residence and began moving the ladder. The ladder had been positioned against the side of the residence and had been used to reach the upper level of the residence, when the workers were scraping and painting the structure. As the victim moved the ladder to a vertical position, it came into contact with an overhead powerline located about 24 feet above ground level and directly above the victim's position. Electrical current passed through the ladder and victim to ground, electrocuting the victim.
1992-30	A 34-year-old male apprentice lineman (the victim) was electrocuted while assisting a co-worker in setting a wooden utility pole. The pole had been raised between two phases of a 34,500-volt overhead powerline and the victim was helping set the pole by steadying the butt over the hole. The victim slipped on the wet ground and his unprotected upper body fell against the pole while the top of the pole contacted one phase of the powerline (19,900-volt phase to ground). The victim was wearing rubber lineman's gloves as required by company policy. The wet connections allowed the current to travel down the pole, entering the victim's chest and exiting to ground through the victim's right elbow. The victim raised up, stepped back from the pole, and collapsed to the ground. Cardiopulmonary resuscitation was initiated immediately by the co-worker and a passing emergency medical technician; however, efforts to revive the victim were unsuccessful.

1992AK012	A 37-year-old male electric utility powerline worker (the victim) was electrocuted while performing maintenance on a 7200-volt overhead powerline. The victim had been assigned by the electric utility to investigate and repair a problem involving intermittent power outages in a rural community. Two weeks before the incident, the victim isolated and replaced what he thought was the outage problem (an arcing electric service line) at a utility pole near a school. On the day of the incident the victim climbed the utility pole to adjust the primary phase jumper cable, which he apparently thought was another probable arcing source. He was not wearing his lineman gloves, or his protective helmet. At the moment of the incident, the victim had his left climbing boot gaff planted in the utility pole, his right climbing boot in contact with the pole guy wire, and his left arm/hand resting on the neutral phase. Thinking (presumably) that the powerline had been de-energized, the victim grabbed the energized primary phase jumper cable with his right hand. In doing so, he provided a path to ground (the electric current entered his right hand, and exited his left arm/hand and right foot), and the victim was electrocuted. The forensic pathologist stated in his report that the victim's judgement was probably impaired by the influence of marijuana which the victim may have used shortly before the incident.
1992CA003	A 56-year-old black male plumber (victim) was electrocuted while doing plumbing repair work underneath a residential home. The victim had been hired by a general contractor to do plumbing repair work at this residence. The contractor had hired the victim on other occasions to do plumbing work for him. The victim was discovered by the contractor at 12:30 pm on Friday April 3, 1992. The contractor stated that the victim was unresponsive when he called to him and that he was located in a crawl space beneath a house. The contractor called 911, and fire department personnel responded and removed the victim from under the house.
1992CA006	A 26-year-old Hispanic male construction laborer (victim) was electocuted when he tripped and came into contact with an energized crane. The victim was in the process of carrying a wire rope over to be used to attach a pile of plywood to the crane's hook. The commotion created by the victim behind the crane, startled the crane operator thus allowing the boom to make contact with a high voltage powerline.
1992CA008	A 31-year-old white male roofer (victim) was electrocuted when he lost his balance and fell on top of two power lines while doing preparations for a roofing job. The victim was in the process of placing a chalk line under the power wires when the incident occurred. The location of the incident was a private residence. There were two co-workers on site at the time of the incident, but the victim was not removed from the electrical source and cardiopulmonary resuscitation was not attempted. The wire insulation had mostly worn off exposing the bare line wires. These wires (two live 110 volt and one ground) were tagged and retained by Department of Water & Power (DWP) for inspection.
1992CA011	A 27-year-old Hispanic male maintenance laborer was electrocuted while doing renovation work in an office building. The victim was removing ceiling tiles and trying to cut an electrical wire when the incident occurred. The victim was electrocuted when both hands made contact with a dangling electrical wire (120 volts). At the time of contact the victim was standing on a step ladder made of aluminum and fiberglass. A co-worker pushed the victim from the ladder immediately after the incident, thus exposing himself (co-worker) to the risk of electrocution. A supervisor summoned to the area phoned 911 and then initiated cardiopulmonary resuscitation procedures. The rescue team arrived a short time latter and continued giving CPR along with defibrillation procedures and transported the victim to the hospital where he was pronounced dead.

1992CA013	A 30-year-old white male pipefitter (victim) was electrocuted while closing a steel chain link gate at a construction site. The victim was leaving the premises at the time of the incident, and was not wearing any personal protection equipment (PPE) other than workboots. An office/trailer which had been used by the construction crew as an office was located immediately adjacent to a freestanding (no post) chain link fence when the incident occurred. It was determined that the grounding wire in the office/trailer was not connected to provide effective grounding when the incident occurred. As a result of this, one side of the gate became energized from the freestanding fence and as the victim grabbed the other gate he completed the circuit to ground. The other gate (side opposite the office/trailer) had posts which ran into the ground. A co-worker pushed the victim from the gate and was shocked. Cardiopulmonary resuscitation was given by co-workers until paramedics arrived.
1992MA001	A 53 year-old electrical lineman died from burns suffered while repairing a damaged utility pole. The victim was in a cherry picker bucket of an articulating line truck (ALT) at the time of the incident. Hydraulic fluid, which flowed through hoses, raised and lowered the bucket. Company and OSHA officials speculated that a massive short-circuit burned through the hoses and ignited hydraulic fluid, engulfing the victim and the bucket in flames.
1992MA003	A 25 year old male self-employed carpentry specialist (victim) was electrocuted after he contacted an overhead energized public utility power line. The victim and an employee had been applying new siding to a private multi-family dwelling and were nearing completion of the project. In the course of dismantling pump jack scaffolding, both men were manning a single 30 foot aluminum staging pole specifically in the effort to avoid both damage to the dwelling AND contact with the powerlines. While both men were apparently succeeding in their efforts to do so, either difficulty in uprighting the staging pole or a gust of wind caused the staging pole to sway resulting in contact with the inner most power distribution line located some 70 inches from the dwelling itself. The point of contact was 13.8 kV line to line with 7,967 volts line to ground. Staging pole contact with the powerline provided a path to ground for the electrical current shocking the employee who was able to break free, yet electrocuting the victim who did not break contact in time to survive.
1992MA010	A 35 year old male elevator service/repair helper (victim) was electrocuted while installing a new electrical component on a commercial elevator car. During the course of this installation, the victim who was working unobserved, came into contact with an energized 110 volt electrical circuit supplying power to an operational single socket porcelain lighting fixture located on top of the elevator car. The victim was attempting connection of the component to the live branch circuit when he was jolted by the 110 volt current. Immediately shaking off the effect of the electrical charge, the victim resumed his work and collapsed approximately 50 - 60 minutes later while standing beside a co-worker inside the elevator car. The co-worker caught the victim as he pitched forward in the elevator car and immediately summoned facility medical personnel that included a company based physician. The victim was then transported to the local hospital where he was pronounced dead 1 hour and 40 minutes later.

1992MA017	On August 03, 1992, a 56 year old real estate developer/builder was electrocuted at a new homesite under construction. While in the process of shutting down a construction site generator for the night, the victim apparently came into contact with a bare electrical conductor. Once the victim was found, emergency medical services were summoned and he was transported to the local hospital were he was pronounced dead approximately one hour later.
1992MN002	A 34-year-old male (victim) electric utility worker died after contacting an energized 4160-volt power line as he was attempting to replace a termination bracket bolt. The procedure took place within one foot of the energized wire, and the lineman was not wearing protective gloves. Earlier, he had had difficulty in handling a ¼" bolt and had to descend from an aerial bucket to retrieve it from the ground after dropping it. The victim had appropriate personal protective equipment available (high voltage gloves, safety glasses, and hard hat). However, according to a coworker, he apparently removed the gloves in order to improve hand dexterity after re-ascending in the bucket. The coworker, acting as an observer, lowered the unconscious victim within one minute of hearing a zap and seeing the slumped, unresponding figure. Emergency medical procedures (CPR and ACLS) were administered within the recommended time limits, but the victim was not resuscitated.
1992MN006	A 44-year-old male plumber/construction worker (victim) died when a lag-bolt he was screwing into a wooden house foundation made contact with one side of an indoor 220V clothes dryer line (110VAC) and he was electrocuted. Due to heavy spring rains, the completely constructed, finished house had sunk approximately three inches into fine, silty soil. The victim was positioning wooden posts outside the wooden foundation and using these as supports to jack up the house. Two of the four posts jutted away from the foundation and required straightening. Chains with lag-bolts attached to both ends were placed around the posts and screwed into the foundation to pull the posts straight. While screwing the second lag-bolt of one of these chains into the foundation, the victim made indirect contact with an indoor 220V conductor and was electrocuted.
1992NJ007	On March 16, 1992, a 60 year-old male journeyman electrician was electrocuted after he contacted an energized electrical cable carrying 277 volts. The incident occurred in an office building which was being renovated to expand the office space. As he was working from a wooden ladder to install two new fluorescent lighting fixtures in the ceiling, the victim contacted the energized cable while attempting to wire the cable to the fixture.
1992NJ011	On May 17, 1992, a 43-year-old male utility company work leader died after he contacted 7,200 volts of electricity while replacing a lightning arrester on a utility pole. The victim and two co-workers had been assigned to replace a step-down transformer and two lightning arresters that had been damaged by lightning. The victim was working in the bucket of a insulated aerial lift truck and removed one of his rubber insulating gloves while replacing a lightning arrester. As he was holding the grounded lightning arrester bracket, his shoulder contacted an energized cut-out switch.
1992NJ019	On July 14, 1992, a 42-year-old male heating and air conditioning company worker was electrocuted while he serviced an energized central air conditioning unit.
1992NJ026	On August 6, 1992, a 61-year-old male utility company lineman was electrocuted when he apparently fell against the energized secondary conductors in an opened ground level steel transformer box. The victim was the work leader of a three-man crew installing underground electrical service in a newly constructed housing development.

1992NJ029	On August 14, 1992, a 35 year-old male construction worker was electrocuted when a crane hoist cable attached to a pump he was handling contacted a 7,200 volt overhead power line. The incident occurred at the site of a road construction project while a work crew was using a crane to lower a water pump into a construction excavation. The victim was pulling the suspended pump into position when the crane cable swung into contact with the overhead power line.
1992WI057	A 27 year old white male working as a tow truck operator for 7 years was electrocuted when the boom he was operating hit a 4800 volt high power transmission line. The victim was attempting to move a junked auto from 2 tiers of junked autos sideways. He was standing on the ground with one hand on the load hook and one on the chain when the boom hit the over head transmission line and he became energized. A co-worker witnessed the incident but was not touching the energized machines/tools. Trained rescue workers were on the scene within minutes of the incident. The worker was pronounced dead approximately 1 hour after the incident.
1993-14	On March 31, 1993, a 20-year-old male truck driver (victim #1) and a 70-year-old male company president (victim #2) were electrocuted when the boom of a truck-mounted crane contacted an energized 7,200-volt conductor of a 3-phase overhead powerline while the driver was unloading concrete blocks at a residential construction site. The driver had backed the truck up the steeply sloped driveway at the residential construction site and was using the truck-mounted crane to unload a cube of concrete blocks while the company president and a masonry contractor watched. The driver, operating the crane by a hand-held remote control unit, was having difficulty unloading the cube of blocks because the truck was parked at a steep angle. While all three men watched the blocks, the tip of the crane boom contacted one of the conductors of the energized overhead powerline and completed a path to ground through the truck, the remote control unit, and the driver. The company president immediately attempted to render assistance and apparently contacted the truck, also completing a path to ground through his body. A passing motorist witnessed the incident, left the scene to summon help, and then returned to render assistance. The motorist successfully used a length of lumber to break the remote control unit tether from the crane, interrupting the path to ground through the driver. The motorist then provided first aid to the driver until relieved by local firemen and EMS personnel who responded within 16 minutes of notification. The driver was airlifted to a nearby burn center where he later died. The company president was pronounced dead at the scene.
1993IA015	A 31 year old employee of an electrical construction firm was electrocuted when the pole he and another employee were installing came in contact with a 7,200 volt distribution line. The employee was wearing a hard hat, rubber boots and muddy canvas gloves.
1993MA003	A 29 year old male carpentry foreman (the victim) was electrocuted when the metal ladder he was moving contacted an overhead powerline. Prior to the incident, the victim and two co-workers had been preparing the facade of a three story multi-family dwelling for a fresh coat of paint. As the crew of three were completing their day's work, the victim and a co-worker were moving a 40 foot aluminum extension ladder which had been positioned against the front of the residence. As the duo moved the ladder to a vertical position, it contacted the overhead powerline located about 24 feet above ground level and directly over their position. Electrical current passed through the ladder and victim to the ground, electrocuting the victim and shocking the co-worker.

1993MA009	On Monday, June 21, 1993 a 32 year old, male, self-employed electrician was electrocuted while connecting a hydraulic press brake at a Massachusetts manufacturer of steel toxic waste containers. Apparently believing that the circuit was de-energized, as he had left it before his break, the victim cut through the taped end of a cable with insulated wire shears. The victim became energized and yelled to his father who was working with him to shut off the breaker. The victim's father turned the breaker off, and the victim collapsed to the floor. Emergency medical services responded within minutes and transported the victim to a regional hospital, where he was officially pronounced dead less than one hour later.
1993MN010	A 42-year-old male journeyman electrician (victim) was fatally injured when he made direct contact with a bare section of an energized 240V electrical conductor in the base of a street light pole. He was not using any electrical personal protective equipment at the time of the incident. He was part of a two-person crew replacing lamp heads on the poles. The victim, working at the base of poles, would remove a fuse to disconnect power to the lamp head, prepare and splice together wires to bypass a ballast located in the base, and reinsert the fuse when work by the other crew member, at the lamp head, was complete. Electrical power from feeder boxes to the base of poles was not shut down during the replacement process so that new lamp heads could be checked for operation immediately after installation. At the time of the incident, work had proceeded to the point where the fuse had been removed and the ballast had been removed from the base of a pole. The victim reached inside the pole to retrieve the now deenergized wire that went to the lamp head to prepare it for splicing. He inadvertently contacted the 240V lead conductor from the feeder box, on the energized side of the fuse, and was electrocuted. Inspection of this conductor showed that approximately two inches of insulation had been gnawed away by rodents.
1993MN062	A 33-year-old male heavy construction equipment field mechanic (victim), repairing a tractor at a residential construction site, was struck and electrocuted by a severed overhead power line. Two other mechanics were in the process of repairing a drive sprocket of an excavator parked 150 feet away from the tractor. The tractor, the excavator, and a tank truck were parked on the curb-side of a residential roadway, beneath a three-phase 8000V power line. To remove the damaged sprocket, it was necessary to swing the excavator boom 180 degrees and use it to raise one excavator track. Despite one mechanic serving as a spotter, the excavator boom hit and severed the power line as it was swung. The line fell across the tank truck, and knocked the victim off of the tractor to the ground. He was electrocuted when it came to rest on top of him.
1993MN079	27-year-old male construction laborer (victim) was electrocuted when he made direct contact with an 8000-volt conductor inside a transformer box. He was not using any personal protective equipment at the time of the incident. He and a coworker were laying plastic conduit for underground cables beneath and up to the bottom of the box. An employee from the local electrical utility company had unlocked the box's outer metal cover earlier so the construction workers could open it and visually monitor conduit positioning by way of its uncovered, secondary, 240-volt, side. Its primary, 8000-volt, side was double covered with an unlocked red fiberglass hood. After unlocking the box, the utility company employee left the site and instructed the workers not to access the primary side of the box. As the victim and coworker attempted to place the 90-degree elbow piece beneath the box's primary side, it entered the box and got hung-up on a ground wire. The victim opened the fiberglass hood covering the primary side and reached inside to move the wire or conduit. As he withdrew his hand, he made direct contact with the 8000-volt conductor inside the transformer box, completed a path to ground, and was electrocuted.

1993NJ019	On March 6, 1993, a 47 year-old male power company chief lineman was electrocuted after making contact with 4,200 volts from an energized power line. The incident occurred when the victim was preparing to splice a length of copper wire to a power line that had broken during a storm. Although the line was thought to have been de-energized, feedback energy was present in the line from an energized transformer bank. The lineman was electrocuted after taking hold of the hanging line to begin the repair.
1993NJ063	On August 9, 1993, a 33 year-old male construction laborer was electrocuted while working in a public school building. The incident occurred in the entrance vestibule where a lighting fixture was hanging down by its electrical cable. At about 8:30 a.m., the victim was in the vestibule apparently carrying discarded tiles outside when a second worker heard him scream and found him clutching a garbage can for support. The second worker (who was the victim's brother and a police officer) went to his aid and started CPR when the victim went into cardiac arrest. It is not known how the victim contacted the electrical energy that killed him.
1993NJ069	On August 18, 1993, a 36 year-old male roofer was fatally injured after falling 30 feet from an wooden ladder when the metal pole of a mop he was holding contacted a 3,600 volt overhead power line. The incident occurred while the victim was climbing up a ladder to the roof of a three story row house. As he was stepping off the ladder to the roof, the aluminum handle of the mop he was carrying contacted the power line, shocking him and causing him to fall to the ground. The victim died of his injuries the next day.
1993NJ089	On October 6, 1993, a 27 year-old male drill rig operator was electrocuted when a radio antenna on top of his drill rig boom contacted a 7,200 volt overhead power line. The incident occurred when the victim and two helpers were preparing to drill a water well in the front yard of a private home. As the victim stood at the controls and raised the boom, the antenna contacted the powerline, energizing the drill rig and electrocuting the victim.
1993NJ126	On December 22, 1993, a 27 year-old male sheet metal worker was electrocuted as he was apparently trying to repair an overhead light fixture. The victim had accidentally damaged the fixture several days earlier while repairing the ventilation ductwork above the light. On the day of the incident, the victim and a co-worker were measuring another area of the plant for new ductwork. After completing the measurements, the victim and co-worker went into the room with the damaged light and set up a small personnel lift. The victim was on the lift apparently trying to remove a nut from an electrical junction box in the ceiling when he contacted 277 volts from the energized circuit.

1993WI214	A 45-year-old male electrician (the victim) was electrocuted when he contacted an energized ½-inch metal-cased electric drill. The victim had been contracted to install electrical wiring in a residence under construction. He was in the process of drilling holes in overhead joists when the incident occurred. There were puddles of water on the cement floor of the work site. The drill was connected to a temporary power pole by a series of three extension cords, two of which were missing the ground pin. One cord was missing outer insulation jacket at both ends exposing the wiring for about ½ inch. The cords extended through the doorway outside to the power pole, where the ends were lying on the ground in puddles of rainwater and mud from recent heavy rainfalls. The cords were plugged into a ground fault circuit interrupter (GFCI) receptacle mounted on the power pole. The power pole had been inspected and certified as meeting local municipality code requirements prior to having the utility company install the meter. However, testing after the incident disclosed the GFCI was inoperative, and the fuse box for the 120 volt single phase 15- and 20-ampere receptacle outlets located at the power pole contained two 40-ampere fuses. After the victim failed to respond to phone calls from the contractor, the contractor proceeded to the work site and found the victim lying face down on top of the drill. The police responded to the contractor's call for assistance and after arriving at the scene, disconnected the power source before examining the victim. The police determined that rigor mortis had set in, and called the coroner to the scene. The coroner arrived 45 minutes later and pronounced the victim dead on the scene. The victim was self-employed, and there were no witnesses to the incident.
1994-08	A 46-year-old male road maintenance foreman (the victim) died and a 20-year-old male road worker was severely burned when the 20-foot-long dump bed of a truck, which was backed against a paving machine they were leaning on, contacted an overhead 7,200-volt powerline. The victim and the road worker were members of a 5-man crew that was paving a 2-lane highway frontage road and an interstate exit ramp. An overhead 7,200-volt powerline ran in a direction perpendicular to the frontage road. One lane of the frontage road had been paved, and the crew was paving the second lane at the time of the incident. The victim was leaning on the paving machine, a road worker was operating the asphalt depth screw regulator while standing on the ground, and two other road workers were positioned at the operator station on the paving machine. The truck was backed up against the paving machine and the victim motioned for the driver to raise the truck bed to allow the asphalt material to flow into the paving machine. As the bed raised, the warning alarm flasher at the left top corner of the truck bed sounded and flashed, then the truck bed contacted the 7,200-volt powerline. The electric current traveled through the truck body and paving machine to the ground through the victim and the road worker. The victim was electrocuted and the road worker received severe electrical burns. The truck driver lowered the bed away from the powerline, and neither he nor the two road workers on the paving machine was injured.

1994-10	On March 14, 1994 a 53-year-old male journeyman wireman (the victim) was electrocuted when he contacted two energized 6.9 kV buss terminals at a power plant. The victim and two co-workers had been engaged in final installation of electrical components associated with a sulfur dioxide emissions control system. These components were being installed in a 14-compartment switchhouse. The circuit breaker protecting the switchhouse's internal buss had been isolated according to the power plant tagout procedures. The victim and co-workers were wiping down the individual compartments in preparation for a pre-startup inspection by power plant personnel. Without the knowledge of the victim and co-workers, the switchhouse's internal buss had been energized by power plant personnel; when the victim attempted to wipe down one of the compartments at the south end of the switchhouse, he contacted the A phase buss terminal with his right hand and the C phase buss terminal with his left hand. This completed a path between phases for 6.9 kV and he was electrocuted. One co-worker was walking past the victim when the incident occurred; he was blown backward from the resulting explosion, and received first degree flash burns on the face and neck. The second co-worker, at the north end of the switchhouse, heard the explosion and came to render assistance. The contractor's safety coordinator was notified by radio and EMS assistance was requested. The EMS responded in approximately 15 minutes and transported the victim to a local hospital emergency room where he was pronounced dead.
1994-17	A 46-year-old male HVAC contractor and his 23-year-old employee (the victims) were electrocuted while installing air conditioning duct work in a crawlspace. The contractor and employee were installing a combination heating, ventilating, and air condi- tioning unit at a private residence. The employee was under a 38-inch-high crawlspace installing aluminum straps around the new duct work, using an electric drill to install screws through the straps. As the employee drilled a hole, the sharp edge of the strap contacted house wiring attached to a floor joist above him, damaging its insulation. This action allowed the drill bit and strap, which the employee was holding, to become energized. The current passed through the employee to ground, either through a cast iron sewer drain pipe or through cold water pipes in the immediate working area of the victim. The contractor, installing duct work in the attic, was summoned to the crawlspace by the residence owner, who had heard noise in the crawlspace. The contractor called into the crawl space for the employee, but did not receive an answer. The contractor entered the crawlspace and grabbed the victim while leaning against the same water pipe as the victim, allowing the current to flow through him to the ground. The owner of the residence pulled the main circuit breaker for the house and called 911. Police, fire, and emergency medical service personnel responded to the scene and, finding both men in cardiac arrest, initiated cardiopulmonary resuscitation. The victims were transported to the local hospital, where they were pronounced dead by the attending physician.

1994CO003	On January 25, 1994 a 38-year old employee of an electrical contractor was electrocuted when an energized jumper wire contacted a guy wire onto which the deceased was holding. The deceased was a foreman of the line crew that was replacing electrical poles and rerouting electrical lines for a local rural electric association. When the incident occurred, the crew was disconnecting power lines from an old pole to allow pole replacement. The deceased had used a climbing belt and boot hooks to climb the pole; he had assisted a co-worker who was positioned in a truck-mounted insulated bucket on the opposite side of the pole. The deceased had accomplished the task for which he had ascended the pole, and was resting prior to his descent. The pole was supported in place by two guy wires, one attached approximately four inches above the other, both wrapped around the pole on metal bands and then secured in place with metal brackets. The workers were disconnecting the remaining two segments of a single-phase 7200-volt line that joined at the pole and were connected with a "jumper wire" (an uninsulated energized wire that allows the electricity to bypass the gap in the two line segments where they attach to the pole). A "hot hoist" (a hand-operated winch and nylon strap with end clamps that are attached to each line approximately two feet away from the pole) had been installed to pull the lines toward the pole, thus releasing tension on the sections of line at the point of connection to the pole. This allows the crew to disconnect the ends of the line from the pole. When the injury occurred, one end of the line had been disconnected. This created slack in the jumper wire. From contact marks on the jumper wire and the guy wire hooks it appeared that the jumper wire contacted the guy wire bracket. The deceased was holding onto the two guy wires and provided the path for the flow of electricity between guy wires and the ground.
1994CO035	On July 19, 1994 several workers were spray-painting the exterior of an industrial building. The workers were using aluminum ladders to access the upper portions of the wall on which they were working. The injured worker descended his ladder, and lifted it from the wall to move it past his coworker and continue painting. As he was moving the ladder in a vertical position, it contacted a 7,620-volt power line. Another coworker hit the injured worker with both hands, knocking him from the ladder, thus breaking the electrical contact. Immediate attempts to revive the worker at the scene were unsuccessful.
1994MA068	On October 24, 1994, a 53 year-old municipal public utility electrician was electrocuted while performing triennial maintenance at a utility-owned electrical substation. Following the removal of a circuit breaker from its cabinet enclosure, the victim entered the enclosure, and came into contact with one of three live electrical conductors carrying 2,400 volts. Discovered by a co-worker, the victim was removed from the enclosure and administered CPR until emergency medical services responded and transported the victim to the regional hospital where he was officially pronounced dead less than one hour later.

1994MD022	A 35-year-old male master electrician was electrocuted while stripping insulation from the energized conductors of a metal-clad (MC) cable. The victim was working alone installing wiring in an emergency egress hallway of a commercial establishment and apparently was unaware that the cable was energized with 277 volts. No personal protective equipment was in use while the electrician was working with the live wires. The victim was unobserved during the event, but was believed to be standing on the ground with the cable in one hand and a wire stripper in the other hand. He was found in the poorly illuminated hall by the employee of another subcontractor who came to the victim's work area to borrow a tool. Upon finding the victim on the floor the worker kicked the foot of the victim to see if he was awake and then noticed the arcing at the victim's chest where he was clutching the cable and the wire stripper. The worker hollered to others to deenergize the power and call 911 to activate the emergency medical services. Another worker at the scene shut off the power to the building, came to the aid of the victim, and found him pulseless. No one on the scene knew CPR. Within five minutes the police responded and the officer initiated CPR. The fire department medic unit arrived several minutes later and continued CPR until transporting the victim to the hospital where he was pronounced dead 70 minutes later.
1994MN012	A 23-year-old male part-time delivery truck driver (victim) was electrocuted when he stepped from the cab of a flatbed truck after its partially extended loading boom contacted a 40,000-volt overhead power line. The incident occurred while the victim and a coworker were picking up excess building materials from two locations on a construction site. While the victim drove the truck between locations, the loading boom was not fully lowered and secured. The two section boom was in a partially extended, inverted-V position with the loading fork resting on the building materials on the truck flatbed. Its elbow or hinge point was approximately 30 feet above ground while the truck was being moved between locations. As the victim drove the truck to the second location, the extended boom contacted the overhead power line. Hearing a loud bang, he stopped the truck and exited the cab to determine what had happened. He was electrocuted when he touched the ground while also contacting the metal frame of a cab-mounted ladder used to climb to the boom operating platform.
1994MO110	On June 17, 1994, a 33-year-old service technician was electrocuted by 220 volts A.C. while repairing a central air condenser unit located outside a residence. The victim had repaired a leak in the condenser coil and was preparing to check for electrical faults. He was kneeling on moist ground in front of the open side of the unit and was in contact with the case on the side of his abdomen. Later testing of the unit revealed that the compressor unit had an internal short, subsequently electrifying the case. The ground wire to the casing had been removed by the victim, and when the compressor shorted out, the victim provided the path-to-ground and suffered a fatal electrical shock.
1994MO127	A 35 year-old apprentice lineman was electrocuted and a journeyman lineman received a flash burn when a 7620-volt energized power supply line contacted the case of an underground pad-mounted transformer. The victim was in contact with the transformer casing, and may have also been in contact with a nearby chain-link fence, when the journeyman lineman pulled the terminal from the transformer. The terminal end broke apart, the co-worker lost control of the line, and it contacted the transformer casing. The workers believed they had de-energized the unit and supply line prior to working on this unit.
1994NJ072	On May 10, 1994, a 30 year-old male apprentice lineman died when he contacted 69,000 volts of electricity from a transmission power line through a wooden utility pole. He was part of a three man crew that was setting new utility poles at an electrical substation.

1994NJ114	On August 23, 1994, a 32 year-old male groundman died when he contacted at least 1,000 volts of electricity as a newly installed transformer was temporarily energized for testing. He was part of a three-man crew that was upgrading an existing electrical distribution system.
1995MN042	A 23-year-old male building renovation contractor (victim) was electrocuted when a steel scaffold contacted an overhead power line. The victim and a coworker were tuck pointing the exterior of a two-story brick building. They had completed the removal of loose mortar from a portion of the building's west wall. The tubular steel scaffold consisted of five individual sections stacked on top of each other. The victim and the coworker rolled the scaffold on casters along the side of a building. Parallel to the side of the building was an 8,000 volt overhead power line. The scaffold was moved to the north end of the building wall and was being moved around a corner and up onto an asphalt parking area. The scaffold had to be raised approximately six inches from the ground up onto the asphalt. The victim walked backward and pulled on the scaffold while the coworker pushed it across the ground. When they reached the corner of the building, the scaffold was turned and positioned at an angle with respect to the building. The victim lifted the leading edge of the scaffold to get the caster closest to the asphalt onto the asphalt . When he lifted the front of the scaffold, the scaffold corner nearest the power line contacted the line. A path to ground was completed through the victim and he was electrocuted. Two employees in the building heard a loud noise when the power line burst and saw the victim on the ground immediately after the incident occurred. They placed a call to emergency medical personnel and then ran outside and began cardiopulmonary resuscitation. Emergency medical personnel arrived within several minutes and transported the victim to a local hospital where he died about one hour later.
1995NJ061	On June 16, 1995, a 28-year-old male municipal utility worker was electrocuted when a backhoe struck a 4,100 volt underground electrical transmission line. A four-man crew was attempting to determine the source of a water leak in front of a private home and had dug a trench to examine the water lines. The victim was standing on the lawn and holding a shut off key that was attached to a water valve when the backhoe severed the electrical transmission cable. The electrical current traveled from the transmission line, through standing water, to a copper pipe, to the metal shut-off key, electrocuting the victim. The backhoe operator was not injured.
1995NJ080	On August 1, 1995, a 36-year-old electrician's helper was electrocuted after cutting an electrical wire carrying 460 volts. The incident occurred in a retail store fitting room where the victim and a co-worker were replacing the overhead florescent light tubes and ballast transformers. The victim had set up a fiberglass ladder in a fitting room and was standing on it as he cut a wire with an insulated wire cutter. As he cut the live wire, he contacted the energized metal cutter while leaning against the grounded metal fitting room door frame. A co-worker saw the victim being shocked and broke the contact by clipping the wire, at which time the victim collapsed against the door frame.

1996-19	A 16-year-old electrical-contractor laborer (the victim) was electrocuted when a de-energized powerline he was coiling on the ground contacted an energized overhead powerline. The victim, a 16-year-old co-worker, and a 25-year-old crew leader were salvaging a 3-phase, 440-volt powerline (no longer in use) from within an oil field. The crew leader, working from an aerial bucket, was releasing the powerline phases from the pole-mounted crossarms, approximately 350 feet away from the two workers, by cutting the tie wires. As the conductors fell to the ground, the two workers on the ground coiled them, then loaded them on a truck. An energized, single-phase 7,200-volt powerline was also present in the oil field. The pole from which the foreman was releasing the conductors was 22 feet from the energized powerline. A second pole, 150 feet from the foreman, and 500 feet from the workers, was much closer to the energized line: 3 feet away, and 3 feet above it. As one of the conductors was released, the tension on the remaining conductors caused the second pole to lean into the energized powerline, energizing the salvage powerline. The victim, holding one of the conductors in his hand, electrocuted. The coworker, standing next to the victim, received flash burns to his face.
1996CA002	A 30-year old male student worker (victim), performing the functions of a laborer, died after the metal combination street light and traffic signal standard (support pole and attachments) he was positioning contacted an overhead high voltage power line. The standard was suspended from a truck-mounted crane and he was attempting to position it over a foundation so it could be secured in place. As he was positioning the standard, it twisted and the street light mast arm contacted the overhead power line. His co-worker, who was helping him position the standard, was seriously burned.
1996CA006	A 25-year-old male well driller, the foreman (victim #1), and a 47-year-old male well driller, the foreman's assistant (victim #2), were electrocuted when their truck-mounted boom made contact with an overhead power line. The line was carrying 6900 volts in one phase of a 12,000 volt (12 Kv) three phase distribution system. It is believed that victim #1 was operating the controls of the boom and that victim #2 was near the truck retrieving tools from a side-mounted toolbox at the time of the incident. Their job had been to use a truck-mounted boom to pull a water well pump from the bottom of a well (approximately 400 feet deep) so that it could be inspected. The water well company had been hired by a financial service company to do the job. The employer stated that his company had done prior work at this location, and that both victims had performed this type of work on numerous occasions. The victims were discovered when neighbors noticed a brush fire and called the fire department. Fire department paramedics arrived first on the scene and were unable to detect any vital signs (pulse or spontaneous respirations) in either victim.
1996CA014	A 40-year old male plumber (victim) died after laying on his work light while installing plumbing under a house being remodeled. The victim was crawling under the house carrying the work light with him. The electrical wire inside the work light's conduit became bare and energized the light's housing. The victim owned his own company and he was the only employee. Training records were not available.

1996MN056	A 36-year-old male skid-steer loader operator (victim) was electrocuted when he touched a dump truck that contacted an overhead power line. The victim was working with a truck driver from another business at the time that the incident occurred. The victim and the truck driver were working together on a project that involved spreading rocks on a residential driveway. The driveway was located in a wooded area with several overhead power lines. The truck driver had been dumping loads of rocks that the victim spread with the skid-steer loader. At the time of the incident, the truck driver was in the process of dumping the last load of rocks. The victim was guiding the truck driver around the trees and power lines. The victim signaled to the truck driver that he was clear to raise the box of the truck into the emptying position. The box of the truck was elevated into the emptying position where it made contact with an overhead power line. At that time, the victim was speaking with the truck driver while standing on the ground and holding onto a bar on the driver's side of the truck cab. The electrical current forced the victim away from the truck, to the ground. A call to emergency medical personnel was immediately placed. The truck driver performed cardiopulmonary resuscitation and artificial respiration on the victim until the emergency medical personnel arrived. The victim was transported to a local hospital and immediately transported by helicopter to the burn unit of another hospital where he died one week later.
1996MO059	A 33-year-old male installer (victim) of a wireless cable TV service was electrocuted when the antenna mast he was raising/installing came into contact with a 7,200 volt overhead power line. Prior to the incident the victim had placed a ladder against the front of the home and had climbed to the roof to test for signal strength with a signal strength meter. It is believed that the victim could not get a signal of sufficient strength at this location from the wireless cable transmitter. He indicated to the property owner that he would raise the antenna to see if they could get any reception. The victim then assembled the mast and antenna and placed it on the ground perpendicular to the front of the house. There was a single-phase, 7,200-volt powerline that paralleled the front of the home. The line was located approximately 12 feet in front of the home and was approximately 21 feet above the ground. As he raised the mast to a vertical position he contacted the power line with the antenna portion of the unit.
1997AK013	On May 5, 1997, a 21 year old, male concrete pump truck operator (the victim) was electrocuted when the boom of the truck he was operating contacted a 14.4 kilovolt (kV) overhead power line. The victim had completed the process of cleaning the pump line with the two lower sections of the boom elevated, in an oblique position relative to the truck. As he collapsed the boom, the end of the middle section touched an overhead high voltage power line. The concrete truck driver (the witness) who was standing in rear of the pump truck and facing the victim, heard a zapping noise. The victim collapsed still holding the remote control box. The witness lifted the remote control box from the victim's hands using a 2x4 wood stud and then checked the victim for a pulse. Emergency medical services were called. The victim was airlifted to the nearest medical center but was pronounced dead on arriva

1997NE030	A 55-year-old senior line technician was killed when a personal protective grounding jumper clamp came loose and came in contact with him, resulting in his electrocution. He and his crew were in the process of aligning suspension clamps which supported shield wires on the electrical transmission towers. He had climbed up an electrical transmission tower to perform the task and had attached his personal protective grounding jumper between the structure (clamp end) and the shield wire (hook end) and was aligning the suspension clamp for the shield wire. The 345,000 volt conductor lines, which are approximately 35 feet below the shield wire, were energized, which was normal for this procedure. The flat faced grounding clamp that was installed on a section of beveled angle iron on the tower structure became disconnected and contacted the victim resulting in his electrocution.
1998MD019	On Thursday, May 14, 1998, a 40-year-old siding mechanic died four hours after falling approximately 25-feet from an aluminum extension ladder. The victim and three other workers were installing aluminum siding on a 2½ story duplex home, when the accident occurred at 3:15 p.m. He was standing near the top of the ladder holding a 9-foot long by 10-inch wide aluminum siding cap. As he rotated the aluminum cap positioning it for installation, one end of the cap touched a utility wire that runs next to the home. Electricity arced to the house, through the aluminum siding cap, shocking the victim and causing him to fall onto the paved alleyway below the ladder. Emergency medical crews arrived within ten minutes. They resuscitated and then transported the victim to the local trauma center. The victim died approximately four hours later, from injuries received from the fall.
1998MO042	On April 13, 1998, a 24-year-old male cable television (CATV) installer (the victim) was electrocuted when the cable wire he was holding contacted a 7,200-volt powerline. The victim was in the process of installing CATV to a customer. The incident site contained two sets of powerline poles. Line #1 was a single 7,200-volt primary line, with a single neutral. Line #2 was a secondary line that ran adjacent to the primary line on a separate set of poles. It contained a 120/220 volt line, a telephone line and the CATV trunk line. The vertical height of the trunk line on Line #2 was slightly higher than the neutral wire on the Line #1. In order to get the cable wire to the customer it had to cross between the primary 7,200 volt powerline and neutral. The victim had climbed Line #2 pole utilizing a ladder and the installed climbing pegs and secured himself with his safety strap. He was attempting to pass the cable wire between the primary and the neutral when the end of the cable wire contacted the primary line. The victim was immediately electrocuted.
1998MO101	On October 6, 1998, a 39-year-old male journeyman lineman (victim) working for an electrical contracting company sustained a fatal electrical contact with an energized lighting arrestor. The victim, coworker, and foreman were working at an electrical substation, which serves a town of approximately 3,500. The city was in the process of switching their electrical service over from a three-phase 4 kV system to a 12 kV system. The victim and co-worker were on the steel framework of the substation tightening up nuts and bolts on the conductors they had installed. The victim worked his way over to the incident point where he sat down on the structure next to the energized lightning arrestor. He then contacted the arrestor with his left hand and forearm. He fell backward breaking contact with the electricity. The co-worker, foreman, and a city worker climbed up to the victim and immediately started CPR. Emergency personnel were summoned to the scene. The victim was transported to a local hospital where he was pronounced dead.

1998NE025	A 41-year-old journeyman lineman, a 38-year-old journeyman lineman and a 24-year-old, all working as cable installers in aerial line construction, were killed when a guy wire contacted an 8,000 volt above ground power line. The 41-year-old and the 38-year-old were electrocuted and the 24-year-old died the following day as a result of electrical burns. There were no witnesses to the incident, but it appears a guy wire was disconnected by the victims and it contacted an 8,000 volt overhead power line that grounded to earth.
1998NJ025	On March 24, 1998, the 41-year-old owner of a sign company and his 60-year-old helper were electrocuted when the sign post they were raising struck a 7,200 volt overhead power line. The company was hired to raise a sign at a gas station that was being renovated. Setting their truck-mounted crane near the corner of the lot, the owner stood on the truck to operate the crane controls. His helper (who was not employed by the company) was on the ground to guide the sign post over a concrete pad. As the owner extended the crane boom, the pole struck a 7,200 volt overhead power line, electrocuting the helper. The owner saw his friend fall and jumped from the truck to help him. He was electrocuted when he contacted the energized truck while on the ground.
1999AK011	A 38-year old laborer/rigger was electrocuted when a cable attached to a helicopter contacted an overhead power transmission line. The laborer/rigger (the victim) and a coworker had completed their assignment of testing new foundation anchors, located below a set of three transmission lines energized to 69 kV. They had just finished moving and attaching rigging cables to two steel beams. The ground crew used a radio in a truck on a nearby access road to request the aerial lift. The transport staging area was 15-20 feet east of the north-south running transmission lines. A helicopter with an attached non-retractable 111-foot cable arrived and hovered. The wind direction was from the east, placing the helicopter upwind from the lines. As the helicopter maintained a heading nearly parallel to the lines, it descended to place the hook and 5-7 feet of the cable on the ground approximately 10 feet south of the load. The co-worker picked up the hook and brought it underneath the helicopter to the beams where the victim was holding the attached rigging cables. Once attached, the co-worker turned to move away from the load and the helicopter. He heard a crack after taking a few steps. He turned and saw the victim stagger away from the beams and collapse. Simultaneously, the helicopter crew heard a crack and saw a flash. The pilot moved the helicopter away from the lines, lifting the load and dropping it nearby. The co-worker then went to assist the victim. Unable to get any response, he ran to a truck to radio for help. Another co-worker standing near the truck went back to the victim and started CPR. After landing the helicopter a short distance away, the pilot exited the aircraft to check the victim's condition. The co-pilot took command of the helicopter and went to retrieve an emergency medical technician (EMT) employed by the company. Several minutes later, the helicopter returned with the EMT. The co-pilot then flew to a refueling area to bring a helicopter with a transport litter to the incident site. The victim was transported to a local medical facility where he was pronounced dead.

1999AK019	On June 17, 1999, a 32-year-old male drill truck operator's helper (the victim) was electrocuted when the mast of a drill rig contacted two-7,200-volt overhead power lines. The victim was assisting a drill rig operator to drill for a local environmental engineering contractor. They had relocated the truck to the front of an industrial lot to drill the last hole. A small flag indicating the well's position marked the location. The marker was near a fence separating the lot from an adjacent road. Above the marker were four power lines that ran parallel to the road. After extending the truck's front outrigger, the operator began raising the drill rig mast to position it over the marker. The victim was standing near the rear of the driver's side of the truck unloading equipment when the mast contacted the high voltage power line. Two workers employed by the contractor were standing several feet from the driver's side of the truck and heard a noise. They saw the victim and the operator frozen to and then collapse away from the truck. One worker went into a nearby building to call 911 as the other worker went to check both men. A worker from the building and a passerby arrived at the site as the first worker returned. Two teams were coordinated and CPR was started on the victim and operator. Emergency medical services arrived minutes later. The victim and the operator were transported to a nearby medical center where the victim was pronounced dead. The operator survived, but was unable to recall details of the incident.
1999TX202	On March 30, 1999, a 44 year-old male foreman (the victim) was electrocuted after he grabbed an energized bayonet fuse on a transformer. The victim and co-workers, under contract with the local utility company, were in the process of changing 12 transformers from submersible to pad mounted dead front transformers at an apartment complex. On the day of the incident the workers were re-energizing the loop after three units had been changed. The three changed units were Nos. 7, 8, and 9 with No. 9 being the last unit to be changed. Units 8 and 10 were used to isolate No. 9 by totally removing the cockable bayonet fuses located on the primary cable sides of each unit. No. 10 had not been changed and was a live front transformer. The fuses energized the primary cable between the transformers. They were returning the units to normal operations by reinstalling the bayonets in Nos. 8 and 10. Unit 8 had been completed and the lineman was working on No. 10. The victim had supervised the change on two transformers and noticed the lineman was having trouble "cocking" the bayonet fuse in No. 10. The lineman was using an 8 foot insulated fiberglass switching stick, or shotgun stick, to install the bayonet fuse. He had hooked the bottom of the bayonet into the lower switch and was trying to cock it or slide down the sleeve in the middle of the tube to reveal the upper metal contact collar to insert into the upper switch. The victim told the lineman to remove the shotgun stick and after removal of the hot stick, the victim placed his left hand on the top edge of the left door of the energized transformer, reached down and grabbed the fuse with his bare hands. This completed the circuit to ground. The flash ignited his clothes and he was electrocuted by 7,200 volts.

2000AK011	A lineman (the victim) was killed after contacting a 17,400-volt charged switch. The victim was part of a three-man crew replacing cables under a switch cabinet. At the time of the accident, the crew was feeding a new cable under the concrete foundation pad below the cabinet. As one worker pushed the cable under the foundation, the victim looped the cable inside the foundation under the cabinet. The victim was using a hot stick to loop the cable but was not wearing his hardhat when his head came either in close proximity to or contacted the charged switch. Crewmembers saw a flash and came around the switch cabinet to where the victim was located. He was found slumped partially in the cabinet. A crewmember used a hot stick to move the victim away from the cabinet and then began CPR. Emergency Medical Services transported the victim to a nearby hospital where he was declared dead from injuries associated with high-voltage electrocution.
2001AK018	On August14, 2001, an 18-year-old male construction materials technician (the victim) died after contacting an energized power line while operating an all-terrain vehicle. The victim was a quality assurance technician at a rock quarry. The quarry site was also used to process, test, and stockpile materials for the nearby road construction project. At the time of the incident, the victim was riding the all-terrain vehicle for purposes other than assigned duties. While cresting one of several piles of crushed rock, the vehicle was stopped or became stuck in the soft material. Approximately 6 feet above the victim's location was a 14,400-volt power line. The incident was not witnessed, and it was surmised from the evidence that the victim stood on the vehicle's foot pedals. The energized power line contacted his back. A co-worker discovered the victim and alerted several other workers in the area. The victim was left in place on the vehicle until he could be safely removed from the vehicle and moved away from the broken power line, which had burned in half and was lying near the location. A supervisor called 911. State troopers, electric utility personnel, and emergency medical service personnel were dispatched. The victim was declared dead at the scene.
2002MI119	On September 9, 2002 a 41-year-old journeyman electrician was electrocuted while he was working on an exterior light pole. He and his partner were replacing non-functioning lights on two-light light poles. One of the new lights installed did not work. His partner was at the top of the pole in an aerial work basket checking the ballast. The victim was kneeling on damp grass at the base of the light pole so he could open the handhole to inspect the wiring and fuses. He was not wearing or using any protective equipment. The wires were energized and carried 277 volts of electricity. Although exactly what occurred is not known, it is possible that the plastic cover over the fuse inside the pole was broken, and when he reached into the handhole to extract the wires, he made contact with the electricity. It is also possible that he extracted the wires from the handhole, and as he attempted to untwist the plastic cover over a fuse, it broke in his hands. However it happened, he made contact with the electricity. When his partner realized what had happened, he descended immediately and severed the victim's contact with a wooden board. Emergency medical care was given at the site. He was pronounced dead at the hospital.

2002MI152	On November 6, 2002, a 23-year old male operator of a guardrail post pounder mounted on a stake truck was electrocuted when the boom of the post pounder contacted an energized overhead power line. The state highway was oriented in a north/south direction. The contract required guardrails on the highway's east and west sides as well as guardrail placement on the south side of an intersecting road. The company had notified MISS DIG and all underground utility lines were marked. The guardrails on the west side of the highway had been set and the employees were placing guardrails on the east side. It was very windy on the day of the incident causing the overhead lines to sway in the wind. Work had progressed between 150-200 feet along the highway shoulder when, while pounding the guardrail post, the boom contacted an energized overhead 14,000 volt power line that crossed the highway in an east-west direction. The contact energized the truck and the victim received a fatal shock. He fell, breaking contact. Coworkers heard "crackling" and looked over toward the post pounder truck. They saw the victim lying on the ground, under the truck. They carefully pulled him clear from the energized truck and called for emergency responders. The victim was declared dead at the incident scene.
2002MI208	On December 5, 2002, a 48-year-old male laborer was electrocuted when a county road commission steel pole-building antenna contacted an energized 14,400-volt overhead power line while the building was being relocated via a state highway. An electric company lineman, a cable company employee, road commission employees and a police escort were on site. The building was positioned on three dollies, two steer dollies at the "rear" of the building and one dolly at the "front" of the building that hooked to the tow vehicle. The lineman dropped the neutral wire from the pole and left the 14,400-volt electrical lines energized. The lineman was present in an aerial bucket positioned on the road shoulder to observe building clearance while the building was being moved. Approximately 75 feet of the building had proceeded under the lines when two employees assigned to the "rear" steer dollies went under the building and began to ratchet each dolly chain to steer the rear of the building onto the road. Near the front of the building a "bolt of lightening" was observed as the building antenna contacted the line. The two employees at the "rear" steer dollies received electrical shocks and fell to the ground. Bystander CPR was initiated and emergency response was called. One of the workers was taken to the hospital and survived, the other worker was pronounced dead at the scene.
2002WA04601	On August 4, 2002, a painter was killed when he fell from the bucket of an elevating boom type manlift after suffering electrocution when he came in contact with an energized overhead powerline. The 48-year-old worker was on his second day on the job with his employer, a painting contractor. The job involved painting the exterior of a multi-story, multi-unit condominium. He was hired on for the duration of the job. Prior to the incident, a supervisor had given the worker a fall protection harness. He was not given any training or instruction in using the lift, he had never used such a lift before. The supervisor then left the worker in order to attend to another task. The worker then got into the bucket of the manlift and raised it to about 35 feet where it contacted an energized 26,000 volt powerline. The worker then somehow fell from the lift and struck the ground. He was taken to a hospital where he was pronounced dead.

2002WA019	"On February 12, 2002 a section of an irrigation system being lifted by a crane contacted an overhead power line killing a 28 year-old construction laborer/operator. The victim was standing on the ground operating the truck-mounted crane to lift a section of an irrigation system into place. He was lifting the end tower of a pivot irrigation circle system onto a dolly so that it could be moved out into the field where it could be attached to the rest of the assembled system. This section was 80 feet longer than previously assembled sections and extended under power lines. It came into contact with a 7620 volt ac power 3 phase system distribution line. The power went through the section, the truck, the operator and into the ground. The victim had one year of experience in the assembly of irrigation systems. He did not belong to a union. At the time of the incident the weather was clear and cold and it was near dusk. He had been working for the company for about a year."
2003-08	On February 24, 2003, a 32-year-old Hispanic painter (the victim) was electrocuted when the metal ladder he was carrying contacted an overhead powerline. Prior to the incident, the victim and his co-workers had been painting a private residence. As the workers were beginning to clean up the job site at the end of the work day, the victim picked up a metal ladder to carry it to the work van. While the victim was carrying the ladder upright to the van, the foreman and several co-workers verbally warned him about the overhead powerline. Several seconds later, the victim's ladder made contact with the overhead powerline and the victim fell to the ground. The foreman and co-workers ran to assist the victim. After a co-worker made several unsuccessful attempts to call for assistance, the foreman went to a nearby home to call 911. When the foreman returned, he performed cardiopulmonary resuscitation (CPR) on the victim who had no pulse and was not breathing. Emergency Medical Services (EMS) and police personnel responded to the scene. The victim was transported via ambulance to a hospital, where he was pronounced dead in the emergency room.
2003-10	On February 13, 2003, a 24-year-old Hispanic painter (the victim) was electrocuted when the metal ladder he was repositioning contacted an overhead powerline. The victim and his co-workers were painting several two-story townhouses. The victim attempted to reposition the 28-foot-aluminum extension ladder he was using. Several seconds later, the foreman heard a buzzing sound and observed the victim gripping his ladder before falling to the ground. The co-workers ran to help the victim while the foreman called 911. The employees performed cardiopulmonary resuscitation (CPR) on the victim, who had no pulse and was not breathing. Emergency Medical Services (EMS) and police personnel responded within 5 minutes. EMS personnel continued CPR on the victim while transporting him to the local hospital. The victim was pronounced dead in the hospital emergency room.

2003-11	On March 25, 2003, a Hispanic painter/caulker (the victim) was electrocuted when the aluminum 40-foot extension ladder he was attempting to re-position contacted a 13.8 kilovolt overhead powerline. The victim was a member of a five-man crew that had been subcontracted to paint and caulk windows and siding on a newly constructed three-story private residence. He had positioned his ladder between the side of the residence and a seven-foot-high wooden fence frame located seven feet, four inches from the side of the residence. A 13.8 kilovolt powerline was located approximately ten feet from the side of the residence, and 24 feet above ground level. The victim was working in an area approximately 26 feet above ground caulking windows and siding. He climbed down the ladder and began to re-position it on the side of the residence. One of the other crew members heard the victim yell and turned to see the victim trying to hold the ladder as it fell backward. As the ladder fell, it contacted the powerline. The victim was holding onto the ladder and was electrocuted. A worker for another contractor on site called 911 from a cell phone, then initiated cardiopulmonary resuscitation (CPR). Emergency rescue personnel transported the victim to a local hospital where he was pronounced dead by the attending physician.
2003IA055	During the fall of 2003, a 53- year-old construction worker was electrocuted at a rural road construction site. A six man crew was on site that day, preparing to install a box culvert. The victim was working with a boom forklift operator to prepare a submersible pump for removing water from the work area. They had unloaded the pump from a pickup truck and had it suspended from the forklift with an 18 ft. (5.4 m) steel cable. The victim first untangled the hydraulic lines that were wrapped around the pump during transportation. The forklift operator was talking to him through the front window of the forklift, and asked if he was clear of the electric lines, and the victim gave him the thumbs-up sign. Suddenly, while they were talking, the forks came in contact with the overhead power lines, and the victim was electrocuted. As he was standing on the ground, hanging onto the two hydraulic lines, the electric current passed through the steel cable, the pump, and the steel mesh lining of the hydraulic lines to reach the victim and the ground. The man was killed instantly, and the hydraulic lines began arcing into dry grass and started a fire. This fire spread to the forklift and a portable power unit for the pump. The forklift operator initially stayed in his machine, then jumped free from the forklift as instructed in prior training, and was uninjured. When firefighters arrived, the victim was lying on the ground in the middle of the fire with the forklift near, but not touching, the power lines.

2003KY115	On July 4, 2003, a 36-year-old male lead electrician died after being electrocuted with 480 volts of electricity. A crew of five licensed electricians were working at an automotive supply manufacturing facility running wires to connect service for two air conditioning units (3-phase; 480 volts; 30 amp and 35 amp) and service for a lighting panel (3-phase; 277/480 volts and 200 amps). The manufacturing facility had been shut down for the holiday, and besides a facilities office worker in the facilities main office, the five men were the only workers at the site and had complete control of the facility utilities (they were the only ones who had the ability to turn on/off utilities at the facility). Normally, everyone who was working directly with wiring or who could come in contact with live electric wires would place their lock and tag on the appropriate breaker or other control device to guard against unexpected energy being released. This time, it was decided by the crew only the job foreman would use his lockout/tagout equipment on the breakers. The victim was sitting in a 4'x 4' junction box with another employee pulling wires to connect two air conditioning units and service to a lighting panel. Having completed the wiring connection for the lighting service, the lead electrician instructed the job foreman to throw on the breaker to the lighting service while he continued to run the wiring for the two air conditioning units. Instead, the foreman thought he was supposed to throw on the breakers for both the lighting service and the air conditioning services, which he did. As the foreman threw on the breakers, the lead electrician was holding the wiring for the air conditioning service in his hand and was electrocuted. Upon the lead electrician collapsing, the foreman summoned emergency services to the facility while another coworker administered CPR to the victim. Paramedics arrived and transported the decedent to a nearby hospital where he was pronounced dead.
2003NE027	On July 12, 2003, at approximately 5:30 p.m., a 55-year-old irrigation system repairman died after he made contact with live electrical wiring on an irrigation system he was repairing. A 55-year-old irrigation systems repairman was killed when he made contact with live wires while working on a booster pump in a center-point pivot irrigation system. The victim was standing above ground level on the system's metal bracing when he made contact with energized wires. A co-worker and a passing motorist saw sparks from the victim's location. As the victim fell from the structure his foot became tangled in the framework. The co-worker and motorist were able to remove the victim. Local emergency personnel were summoned. They transported the victim to a local hospital where he was pronounced dead.
2004CA004	Two heavy equipment mechanics, an 18-year-old male and a 40-year-old male, died when electrocuted while working on a scraper. The scraper was at a construction site parked under a high voltage line. The victims were using the truck-mounted crane on one of their service trucks to assist in replacing the rear differential when the incident occurred. The crane's boom made contact with the high voltage line. The control for the crane was a remote unit electrically wired to the truck. The 18-year-old victim was operating the crane at the time of the incident.

2004MA038	On October 9, 2004, a 40-year-old roofer (victim) was fatally injured and a co-worker was seriously injured when the aluminum extension ladder they were unloading from a pickup truck contacted a 7,620 volt energized overhead power line. The day of the incident, a Saturday morning, the victim and the co-worker were at the incident site dropping off material and equipment for a job scheduled to start the following Tuesday. The pickup truck was parked in front of the customer's house while the victim and co-worker were lifting the extended aluminum extension ladder from the pickup truck and moving it into a vertical position. The extended aluminum extension ladder came in contact with the energized overhead power lines electrocuting the victim and seriously shocking the co-worker.
2004NE002	A 27-year-old Spanish-speaking masonry laborer was killed when he contacted an overhead electrical line. The victim, along with a co-worker, had raised a bucket truck's personnel platform approximately 30 feet in the air. They were attempting to maneuver the personnel platform above and across some electrical wires in an attempt to clear ice and snow from a building's roof and gutters. When it was determined they could not safely reach it from the current position, the co-worker started to lower the bucket. The victim, for unknown reasons, contacted one of the overhead electrical lines with his left hand. The shock caused him to arch his back and fall outside the bucket, hanging by his harness and lanyard. The co-worker yelled at the victim but got no response. He used his cell phone to call 911 for help, then lowered the victim to the ground. Emergency personnel responded almost immediately and provided emergency care. The victim was transported to a local hospital where he was pronounced dead a short time later.
2005-01	On October 12, 2004, a 26-year-old Hispanic laborer (the victim) was electrocuted at a materials storage yard, as he guided an auger being lifted by a truck-mounted crane onto a truck. A 7,200 volt overhead power line ran through the middle of the 5-acre materials storage yard. The victim was holding on to the auger when the truck boom moved, apparently causing the crane boom or load line to contact the power line, and the electricity to flow through the victim's body. Two workers employed by another subcontractor that were assisting the victim were also shocked and knocked to the ground by the electric current. They were not permanently injured. The crane operator saw that the three employees had fallen to the ground. He came down from the crane operating position and ran to check on the men and look at the crane boom, the load line, and the power lines. [Since the crane operator was not shocked, it is assumed that he moved the boom away from the power lines before exiting the crane cab.] He then ran back to the operating position, lowered the auger to the ground, and then returned to the men. Finding that the victim had no apparent pulse and did not appear to be breathing, the crane operator began cardiopulmonary (CPR) resuscitation efforts. One of the workers who had been shocked ran to a nearby building to call 911, while the other waited for Emergency Medical Services (EMS). EMS personnel responded within approximately 20 minutes and continued CPR on the victim. The victim remained unresponsive and was transported by ambulance to a nearby hospital, where he was pronounced dead by an emergency room physician. The two injured workers were transported to another hospital in the area and examined. One of them was released that day, and the other was admitted to the hospital and released two days later.

2005-02	On November 3, 2004, a 44 year-old Hispanic laborer (the victim) was fatally injured after being electrocuted through indirect contact with a 7,200 volt overhead power line. A boom truck with an auger attached (Photo 1) was turning a utility pole anchor in an anchor-setting process in preparation for a utility pole replacement. During the process, the anchor began to wobble and the extended boom contacted the overhead power line. Apparently unaware that the boom was in contact with the overhead power line, the victim grabbed the energized anchor with both hands in an attempt to stabilize it and remained in contact with the energized anchor until the boom was moved away from the power line. Electrical current moved through the victim's body from his hands to ground through his feet. The boom truck operator immediately called 911 on his cell phone and emergency medical services (EMS) arrived in about 4 minutes. CPR was immediately initiated and the victim was transported to the hospital where he was pronounced dead.
2005MI065	On Friday, July 1, 2005, at approximately 12:20 p.m., a 36-year-old Hispanic brick mason was electrocuted. The decedent was attempting to insert a 20-foot 1/2-inch rerod down through a grouted brick wall he and his coworkers had constructed when the rerod contacted an energized, primary 4,800-volt single-phase powerline. Emergency personnel arrived shortly thereafter and transported the decedent to a hospital where he was pronounced dead.
2006MA043	On October 23, 2006, a 24-year-old male apprentice electrician was electrocuted by an energized 480-volt, three-phase circuit while permanently wiring a heavy duty disconnect switch for a new elevator. The supply side of the disconnect switch had three energized wires fed into it through the switch's top mechanical lugs. At the time of the incident, the victim had just finished disconnecting the three energized wires from the switch's top mechanical lugs and came in contact with an energized source, either a wire or the switch housing, and was electrocuted. A co-worker noticed a bright flash and, upon investigating the source of the flash, found the victim slumped on the ground of the elevator mechanical room. The co-worker yelled for help and started to attend to the victim. A second co-worker entered the elevator mechanical room and then placed a call for emergency medical services (EMS). Both co-workers administered cardiopulmonary resuscitation (CPR) until the arrival of EMS a few minutes later. The local police and fire departments were also notified and responded to the incident site. EMS transported the victim to a local hospital were the victim was pronounced dead.
2006NJ076	On August 17, 2006, a 21-year-old Hispanic male day laborer was electrocuted when the aluminum extension ladder he and a co-worker were carrying in an upright position contacted a 13-kilovolt (KV) overhead power line. The ladder, missing a pulley to adjust the length, had been retrieved from a pile of damaged ladders at the general contractor's storage yard. The worker, an immigrant from Guatemala, had been on the job for three days. The incident occurred at a condominium complex where his employer, a subcontractor, had been contracted to remove and replace roofing shingles
2008CA006	A 34-year-old male Hispanic laborer working for a solar energy company fell 35 feet from a scaffold to the ground below after being electrocuted. The victim was standing on the scaffold and lifting a 20-foot aluminum bracket from the ground. When the metal bracket reached the top of the scaffold, the victim pulled on one end of the bracket. The other end of the bracket contacted high voltage electrical lines approximately 10 feet away from the scaffold, and the victim was electrocuted. The victim fell from the scaffold approximately 35 feet to the ground below. The FACE investigator determined that, in order to prevent future electrocutions among solar energy workers:

2008KY065	On a late summer day in 2008, a 29 year-old male lineman (decedent) was electrocuted while restoring service to a residence. The lineman and three other (out-of-state) employees assisted a local Kentucky power company in restoring power due to outages because of a severe wind storm. The decedent was wearing insulated electrical gloves and sleeves. He was working in an elevated bucket on a live 110 V line when he came in contact with a live wire. A witness saw the decedent shake and slump down in the bucket. The crew brought the bucket to the ground and removed the decedent from the bucket and began to administer first aid. Emergency medical services were contacted. They arrived and transported the decedent to the nearest trauma hospital where he was pronounced dead.
2008MI037	On June 2, 2008, a 47-year-old male journeyman lineman/foreman was electrocuted during the installation of a new 15 KV switch for a single phase, 7,200-volt overhead power line suspended from a wood pole. The decedent was working from an insulated aerial bucket. He had not de-energized the can arrestor fastened to the side of the transformer. He had removed his lineman's gloves prior to removing the first lower bolt of the arrestor. His coworkers believe the can arrestor tipped and the decedent attempted to catch it with his right hand. The current passed through his right hand, across his chest and exited his left hand, which was in contact with a second energized conductor. The decedent yelled to his ground man to lower the bucket. When the bucket was lowered, the decedent was still breathing, but unconscious. The ground man yelled to a two-person journeyman line crew working approximately 200 yards away to come over to help lift the decedent from the bucket. After taking the decedent out of the bucket, the crew began CPR while the ground man called his supervisor for assistance. The supervisor called for emergency response. Arriving six minutes later, the emergency response personnel took over medical care, and then transported him to a local hospital where he was declared dead.
2010MA019	On August 3, 2010 a 23-year-old male laborer (victim) was electrocuted and two co-workers were severely shocked when the 32-foot aluminum ladder that was part of a ladder platform hoist came in contact with energized overhead power lines. The victim and the two co-workers were in the process of raising the ladder from a horizontal position on the ground to a vertical position against a building. While raising the ladder to the vertical position, the workers lost their footing and the ladder fell towards and came in contact with energized overhead power lines. Two co-workers were shocked and thrown to the ground. The victim was electrocuted and the ladder fell to the ground landing on top of him. Once the two co-workers regained mobility, they went to assist the victim. One of the coworkers placed a call for emergency medical services (EMS) and then placed a second call to the employer. The local police arrived followed by EMS within minutes of the call. The victim was transported to a local hospital where he was pronounced dead.

2012WA019	On June 07, 2012, a journeyman framer acting as a rigger was electrocuted when a boom truck's crane hoist line contacted an overhead power line. The 34-year-old victim was employed by a framing contractor. The victim, who was the site lead framer, and two other framers had been working on a new two-story, single-family residence for 15 days. On the day of the incident, an employee of another contractor was operating a telescopic boom truck crane to deliver trusses and lumber. In order to make room for delivery of the trusses, the victim asked the crane operator to lift two bundles of OSB sheathing to the residence's second floor. The victim used a steel chain to rig an OSB bundle. The crane operator then lifted the bundle slightly and the victim placed blocks under the bundle so that he could place a second chain around it. As the victim was placing a second chain around the bundle in preparation for the lift, he grabbed the crane's hoist line in order to hook the chain. The line was in contact with a 7,200 volt overhead power line and carried electric current to the victim. He was electrocuted and died two days later.

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