Lessons Learned: An Analysis of Fatal Electrical Events in Construction, 2005 - 2012

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This report is based upon OSHA-inspected fatal events in the construction industry during calendar years 2005 to 2012. The work was performed by Lucas C. Stewart, B.S. Candidate, Intern, under the direction of John Wagner, M.S., Research Associate, for the Construction Industry Research and Policy Center (CIRPC), The University of Tennessee, Knoxville.

Abstract

U.S. construction is a hazardous industry, and electrocutions represent one of the 'Fatal Four' in construction according to the Occupational Safety and Health Administration (OSHA). To better understand electrical accident features, a detailed analysis was undertaken of 305 fatality case files compiled by Certified Safety and Health Officers (CSHOs) for OSHA during the period 2005 to 2012. Common safety issues were identified and recommendations developed aimed at improving electrical safety practices through an analysis of fatality causes, contributing factors (secondary causes), and employers' safety and health programs.

Results showed that contacting overhead power lines is the primary electrical danger in construction, causing 52% of electrical fatalities. Proper procedure not followed, inattention and inadequate training are the leading secondary causes, contributing to 60% of electrical events. Fatality cause analysis suggests that different forms of training are needed across construction sectors, work types and occupations.

The majority of employers (over 60%) examined were lacking basic safety and health program components, and existing plans were largely inadequate. In creating or improving safety and health programs, the writers found that employers should focus their resources based on size and industry characteristics or based on the projects in which they are engaged. Standards violated and penalties assessed were also analyzed. Results indicated that current OSHA fines alone are unlikely to encourage employers to establish safety programs or enhance existing programs. Significantly higher financial penalties and educational and training initiatives are suggested as viable options for reducing fatalities.

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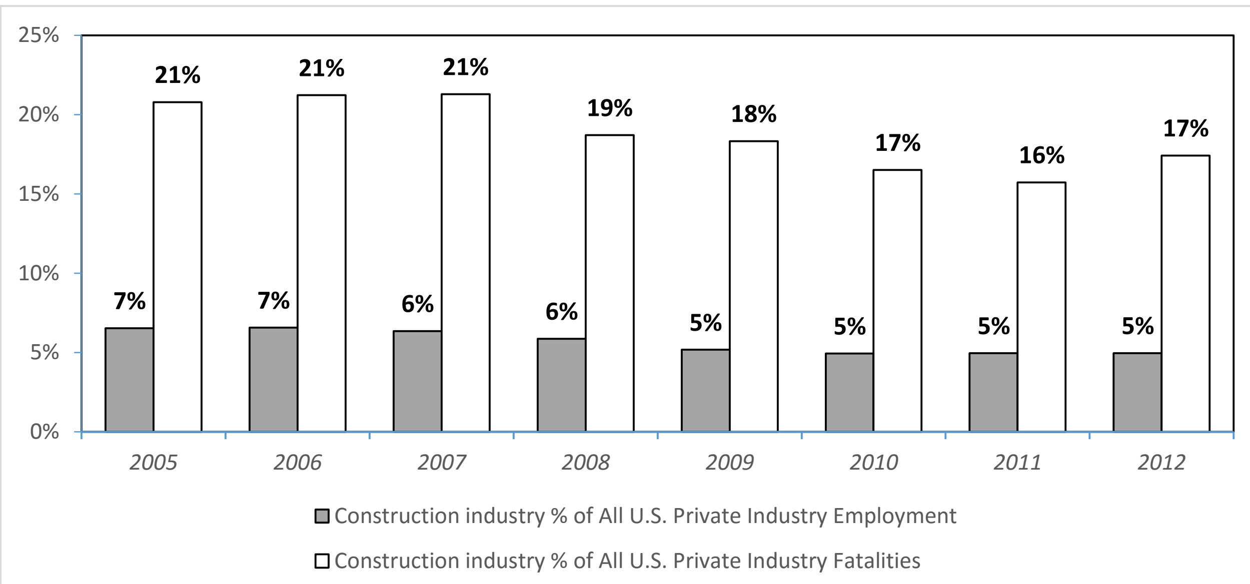
I. Introduction

Construction is one of the most dangerous industries in the United States, and on-the-job fatal accidents in U.S. construction are a significant problem. From 2005 – 2012, the construction industry comprised approximately 6% of total U.S. private industry employment, yet it accounted for almost 19% of U.S. private industry fatalities (see Figure 1). Despite efforts to reduce the risk of occupational injuries in construction, the industry continues to account for a disproportionate share of work-related injuries.

Figure 1. Construction Industry as a Percentage of All U.S. Private Industry Employment and Fatalities, 2005-2012.



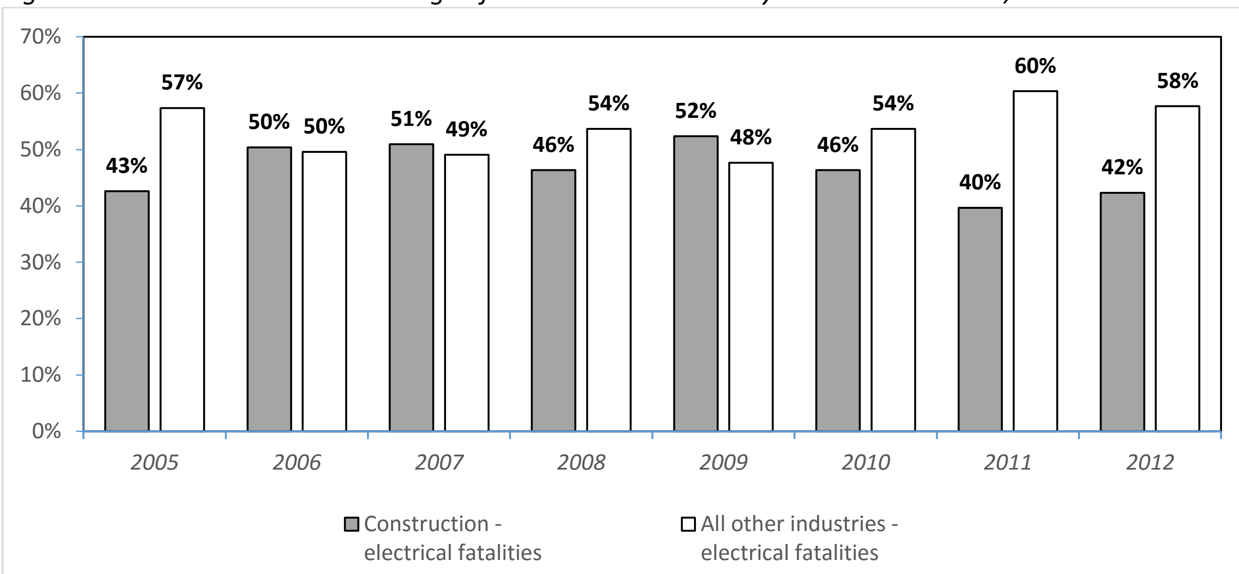
(U.S. Bureau of Labor Statistics (BLS), Census of Fatal Occupational Injuries (CFOI), Current Employment Statistics (CES), 2015)[1,2]

Electrocutions are one of the leading causes of death in the U.S. pervading all of private industry as shown in Figure 2, which compares electrical fatalities in construction with similar fatalities in all other U. S. private industries. While the number of deaths in construction is typically less than in

[1] Employment numbers are not seasonally adjusted and represent the total number employed in the respective industry for December of the corresponding year.
[2] "All U.S. Private Industry" includes both wage and salary and self-employed workers.

general industry, the rate of electrical fatalities in the construction industry is consistently above the private industry average.

Figure 2. Construction as a Percentage of All U.S. Private Industry Electrical Fatalities, 2005-2012.



(U.S. BLS, CFOI, 2015)

For 2003 to 2011, the electrocution rate for construction was 1.5 deaths per 100,000 full-time construction workers, while the private industry average rate was 0.2 per 100,000 full-time workers, indicating that the construction electrocution rate is more than seven times that of the all industry average.

The importance of electrocutions in construction has been recognized by the Occupational Safety and Health Administration (OSHA) which has identified them as being among the “Fatal Four”, which represent the leading causes of worker deaths on construction sites. The events that comprise the fatal four are: (1) Falls; (2) Electrocutions; (3) ‘Struck by Object’; (4) ‘Caught-in/between’. From 2005 to 2012, comparing the ‘Fatal Four’ events between construction and total U.S. private industry, electrocutions (47%) are only exceeded by falls (48%) (see Table 1).

Table 1. Construction as a Percentage of All U.S. Private Industry 'Fatal Four' Events, 2005-2012

Event	*Construction Total* N (%)	*All U.S. private industry total* N
Falls	2691 (48.4%)	5558
Electrocutions	730 (46.5%)	1569
Struck by Object	759 (18.8%)	4039
Caught-in/between	286 (15.1%)	1889

(U.S. BLS, CFOI, 2015)

While the mission of OSHA is the reduction of workplace deaths, injuries and illnesses, this study focuses on fatalities in the construction sector. The objective of the present study is to identify common safety issues through an examination of electrical accident features in construction and to develop recommendations aimed at improving electrical safety practices.

II. Literature Review

A number of studies of electrical fatalities have been conducted. What follows is a summary of a number of major studies. A National Institute for Occupational Safety and Health (NIOSH, 1998) report covering worker deaths by electrocution in all industries from 1980 to 1992 illustrates the magnitude of the national electrocution problem, and the fatality rate calculations allowed for comparison of risks across different factors (e.g., age and occupation). Cawley and Homce (Cawley, 2003) examined occupational electrical injuries, both fatal and nonfatal, in the U.S. over the years 1992 to 1998, and were able to identify key problem areas in electrical safety. Through their analysis, they suggested policies aimed at reducing the frequency and severity of electrical occupational injuries. They also noted the need for further electrical safety research and proposed several areas of opportunity. Janicak (Janicak, 2008) analyzed differences in the proportions of electrocutions in construction, finding that the proportion of electrical fatalities in construction was significantly higher for young workers (16 to 19 years old) when compared to all other industries. Chi et al. (Chi et al., 2009) performed an in-depth analysis of electrical fatalities in Taiwan's construction industry. Their research developed a coding system to aid in the categorization of fatal electrocutions. They suggested that the coding system could be used to derive potential risk factors and establish effective electrocution strategies. Cawley (Cawley, 2013) built on the NIOSH report, covering similar topics for the years 2003-2009, and complemented the results by showing support for the high frequency and rate of electrocutions experienced in construction when compared to all other industries. The Construction Chart Book, published by the Center for Construction Research and Training (CPWR, 2013), examined electrical fatalities in construction, and provides a useful numerical presentation of the risks experienced in this sector.

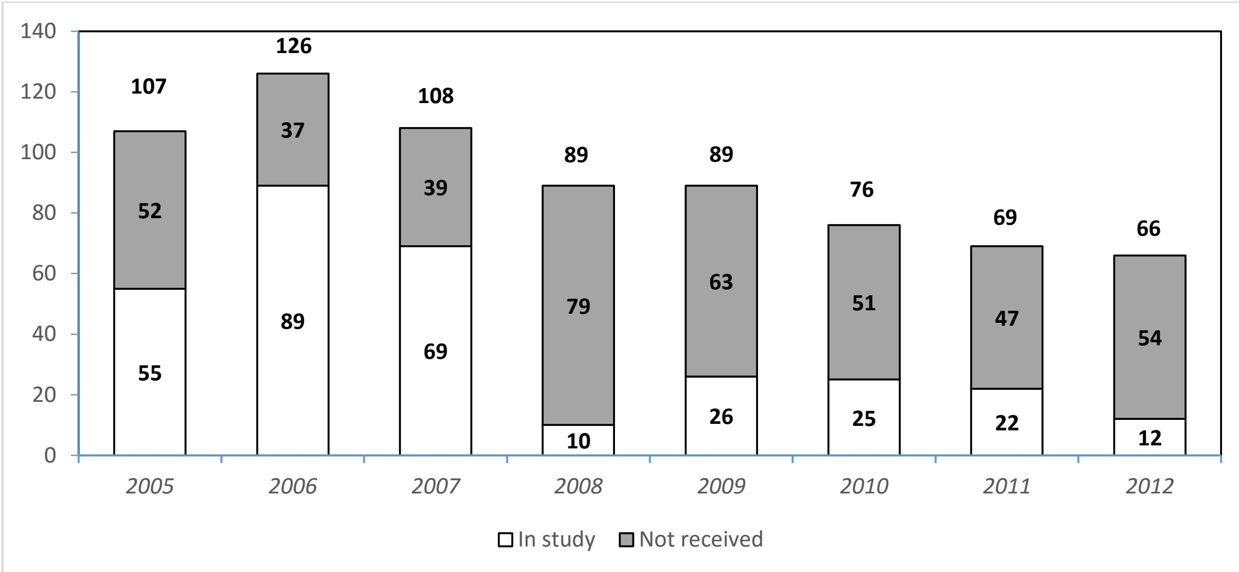
The current study builds on the content analysis and information developed by Zhao and his associates (Zhao et al. 2013) in their analysis of 132 NIOSH FACE (Fatality Assessment and Control Evaluation) reports and extends their findings by considering additional observations as well as unique areas of inquiry. The extent to which the Zhao findings and those of this study are complements will be noted later in this study.

III. Data and Methods

Data Source and General Methods

This study of electrical fatalities examines case files of OSHA-inspected fatal electrical events under both Federal and State jurisdiction during the period 2005 to 2012. The case files, provided by OSHA, consist of electrical fatality narratives and coded data for 305 fatal events inspected by Certified Safety and Health Officers (CSHOs) which accounted for 308 fatalities (three events examined resulted in multiple fatalities). These 308 fatalities represent 42% of the 730 electrical fatalities in construction from 2005-2012 (see Figure 3). Each case file provides details on the circumstances of the fatal event, accompanied by a narrative supplying a brief description of the event. A review of the 305 case files was conducted manually, and incident details, as reported, were collected as input data. From these data, groupings categorizing and describing the records emerged.

Figure 3. Fatal Electrical Events in Construction by Year, 2005-2012.



(U.S. BLS, CFOI, 2015)

Data Methods - Primary and Secondary Causes

For purposes of analysis and recommendations, a primary cause was assigned to each incident. The collective judgment of the researchers was used to analyze and classify the narratives into one of three primary cause categories. However, when the narrative description was omitted, inconclusive, or entirely unclear, the fatal event cause was coded as "Unknown". The following three primary causes of electrical fatalities were used in classifying the 305 fatal events: (1) *Contacting overhead power line*, (2) *Using/working on electrical tools/components and* (3) *Other contact and electrocution*.[3] Secondary causes (contributing factors) for each fatal event were also established.[4] The three primary causes, disaggregated by their associated secondary causes are displayed in Table 2.[5,6]

[3] Primary causes of electrical fatalities are those classified as first in rank or importance with regards to causes of the fatal event, i.e. direct causes.

[4] Secondary causes are not necessarily mutually exclusive. By definition, these contributing factors precede in occurrence the primary cause.

[5] As there was an average of about three secondary causes per primary event, primary column totals will sum to be greater than the 308 fatalities examined – there were 899 total contributing factors.

[6] Percentages displayed in 'Column Totals' and 'Row Totals' represent that respective column or row total relative to the overall secondary total (899). Percentages displayed in individual cells represent that cells total relative to the respective column total.

Table 2. Primary Cause by Secondary Causes

	Primary Cause			
Secondary Causes	*Contacting overhead power line* N (%)	*Using/working on electrical tools / components* N (%)	*Other contact and electrocution* N (%)	**Row Totals N (%)**
Proper procedure not followed (No LO/TO, PPE, etc.)	148 (32.0)	108 (31.9)	14 (14.4)	**270 (30.0)**
Inattention	116 (25.1)	27 (8.0)	3 (3.1)	**146 (16.2)**
Inadequate training	37 (8.0)	67 (19.8)	20 (20.6)	**124 (13.8)**
Victim unaware source energized	40 (8.6)	31 (9.1)	14 (14.4)	**85 (9.5)**
Contacted electrical component during unrelated task	38 (8.2)	3 (0.9)	22 (22.7)	**63 (7.0)**
Tool contact with energy source	18 (3.9)	22 (6.5)	3 (3.1)	**43 (4.8)**
Competent person not present	25 (5.4)	11 (3.2)	0	**36 (4.0)**
Employee misconduct	9 (1.9)	21 (6.2)	2 (2.1)	**32 (3.6)**
Weather conditions	6 (1.3)	13 (3.8)	0	**19 (2.1)**
Used damaged tool/spliced cord	0	11 (3.2)	5 (5.2)	**16 (1.8)**
Contacted a non-electrical component that was faultily energized	3 (0.7)	1 (0.3)	12 (12.4)	**16 (1.8)**
Language barrier	11 (2.4)	4 (1.2)	0	**15 (1.7)**
Drugs, alcohol, prior health condition	7 (1.5)	5 (1.5)	1 (1.0)	**13 (1.5)**
Improper labeled source	0	9 (2.7)	0	**9 (1.0)**
Slipped/fell onto energy source	0	6 (1.8)	0	**6 (0.7)**
Not routine task	5 (1.1)	0	1 (1.0)	**6 (0.7)**
Column totals N (%)	**463 (51.5)**	**339 (37.7)**	**97 (10.8)**	**899 (100)**

Data Issues

The fatality case files made available to the Construction Industry Research and Policy Center (CIRPC) were believed to be the most complete and accurate descriptions of the events. A review of each case file provided by OSHA revealed that coded data for an event did not always fit the corresponding narrative record, and in some cases there were inconsistencies within narrative records. In attempting to gather information on both the existence and sufficiency of employers' safety programs, a lack of full reporting was evident. Because an analysis of employers' safety programs is desirable and could prove useful to both OSHA and its stakeholders, our analysis was conducted under the following assumption: all safety program component entries reported as "Unknown" were changed to "No".

Industry Relevance and Analysis Areas

Combining common data elements into factors facilitates the analysis of information. For the current study, the elements of interest are: (1) Primary causes; (2) Secondary causes (Contributing factors); (3) Employers' safety and health programs including written safety policy, safety training programs and enforcement; and (4) Settlement information covering OSHA standards violated and penalties assessed.[7,8] Both primary and secondary causes were analyzed across each of the following factors in an attempt to gain useful industry insight: (1) Victim's age; (2) Employer's industry; (3) Work type (electrical or non-electrical); (4) Victim's occupation.[9,10] To better understand employers' safety and health programs, an analysis of employers' characteristics was conducted including project type and

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[7] Written safety policy was evaluated as follows: Is there a written safety and health program, and if so, how does it compare to OSHA guidelines?

[8] A safety training program was evaluated as follows: Does the employer have a safety training program in place, and if so, what is its rating?

[9] Occupations were classified based on the collective judgment of the researchers, and were made in relation to occupations presented in the original.

[10] North American Industry Classification System (NAICS) codes were used in the classification of Employer's industry. NAICS groups establishments in to industries based on the activity in which they are primarily engaged.

firm size.[11] The components of the employers' safety and health programs were examined across employer's industry, project type and secondary causes. To further explore the impact of training programs, the inadequate training element was analyzed across the proper procedure not followed, inattention and employee misconduct elements. Due to the large number of secondary causes present in this study, our analysis has been restricted to the top eight secondary causes, which account for 89% of the total secondary causes.

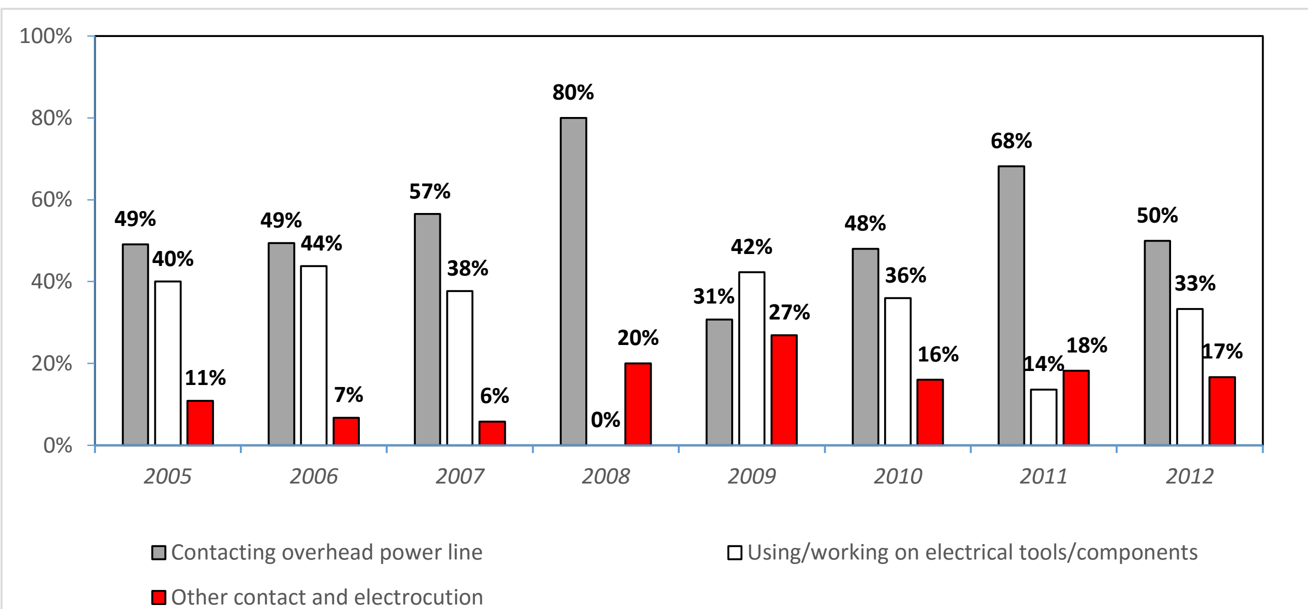
IV. Study Results

Analysis of Primary Causes

Overview

The trend of the primary causes of electrical fatalities for 2005 – 2012 is shown in Figure 4.[12]

Figure 4. Primary Cause Trend, 2005-2012



[11] Project type classifications were made following the NAICS subindustry components of NAICS on https://www.census.gov/econ/isp/index.php under 'Construction'.

[12] *Using/working on electrical tools/components* was not a primary cause for events covered by the current study in 2008.

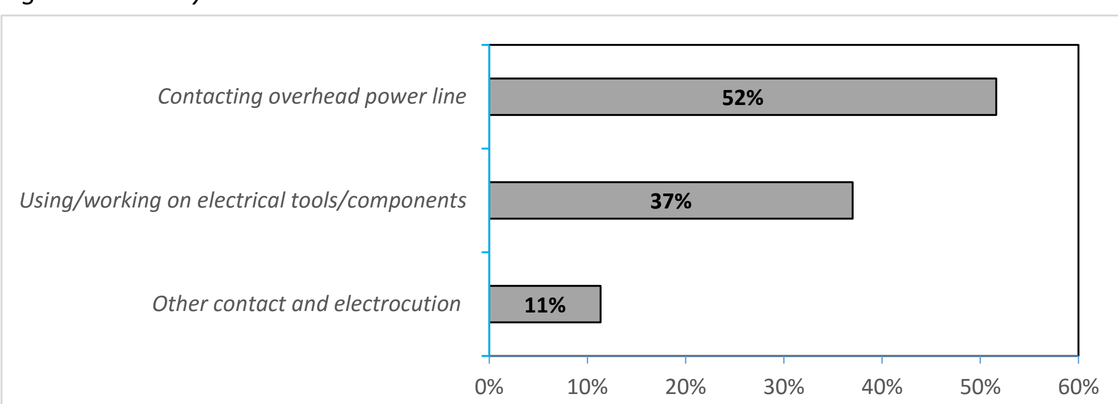
This analysis shows that Contacting overhead power line was the primary electrical hazard in construction. To better assess the hazards surrounding overhead power lines, information was also gathered to determine what contacted the power line. The agent(s) touched are presented in rank order in Table 3.

Table 3. Agent(s) Touched

Agent	*N*	*%*
Crane, boom, lift equipment	51	32.1
Direct body contact	38	23.9
Handling materials	22	13.8
Ladder	20	12.6
Scaffold	16	10.1
Building parts	12	7.5
Total	**159**	**100**

For comparative purposes, primary causes are aggregated and shown as percentages in Figure 5. Note that the two leading primary causes of electrical fatalities account for 89% of the total fatalities examined in the current study. The percentages presented in these analyses describe frequencies of incident characteristics. Percentages do not necessarily reflect the risk to workers, but rather the problem's proportional magnitude.

Figure 5. Primary Cause



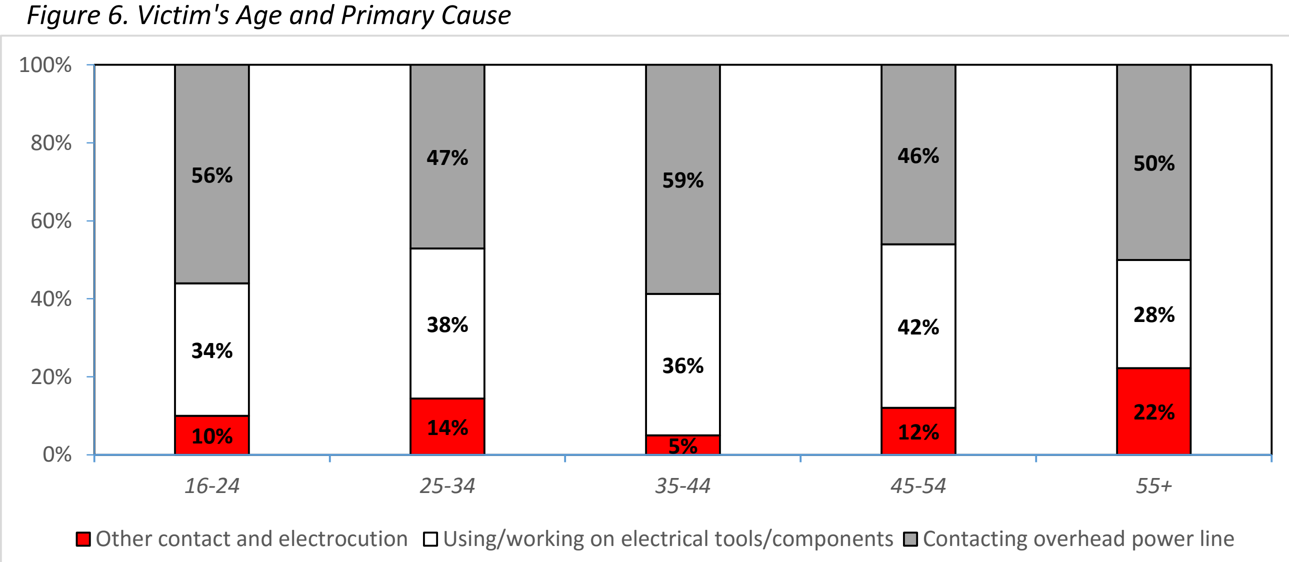
It may be helpful to describe examples of frequently occurring specific situations leading to the three primary causes of electrical fatalities.

1. _Contacting overhead power line_: (1) A construction laborer carrying a ladder makes accidental contact with an overhead power line. (2) An operating engineer, unaware of overhead power lines, makes contact with a wire through the boom of a truck; a worker on the ground touches the vehicle and is electrocuted.
2. _Using/working on electrical tools/components_: An electrician fails to de-energize and/or lockout/tag-out circuits while working on a light fixture and is electrocuted.
3. _Other contact and electrocution_: A plumber working in the crawlspace of a home makes accidental contact with live wires with degraded insulation/covering and is electrocuted.

Frequency Distributions

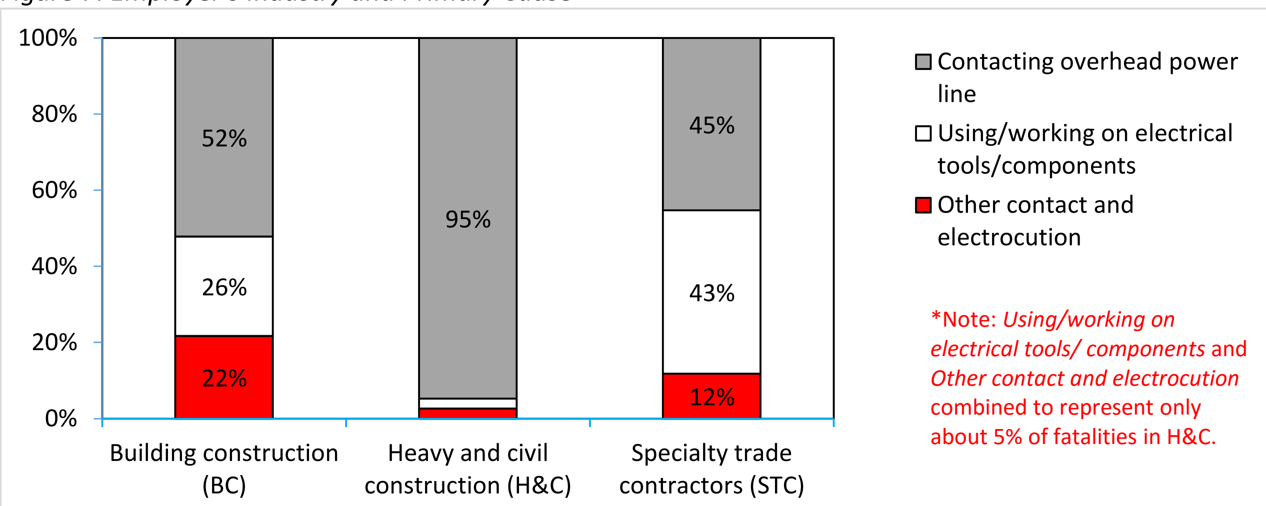
The primary fatality causes for each age group can be seen in Figure 6. Previous researchers have found that age has a significant association with primary fatality cause. For example, Janicak (Janicak, 2008) found that younger workers were more likely to make contact with overhead power lines while older workers were prone to contact with electrical wiring, transformers and related equipment (this primary cause is equivalent to Using/working on electrical tools/components in the current study). We found a rather mixed picture.

Figure 6. Victim's Age and Primary Cause



An analysis of primary causes within construction revealed some interesting results as seen in Figure 7. Contacting overhead power line was the leading primary cause, but differences emerged depending on the sub-sector. Contacting overhead power line accounted for 95% of the fatalities in heavy and civil construction (H&C), 52% in building construction (BC) and 45% in specialty trade contractors (STC).[13] Using/working on electrical tools/components accounted for 43% of STC fatalities, 26% of BC fatalities, and about 3% of H&C fatalities.

Figure 7. Employer's Industry and Primary Cause



In the current study, electrical workers accounted for 46% of fatalities, while non-electrical workers represented 53%.[14] Figure 8 shows the distribution of work type (electrical or non-electrical) among the primary causes. For electrical workers, the leading primary cause was Using/working on electrical tools/components (67%), and Contacting overhead power line (71%) led for non-electrical workers.

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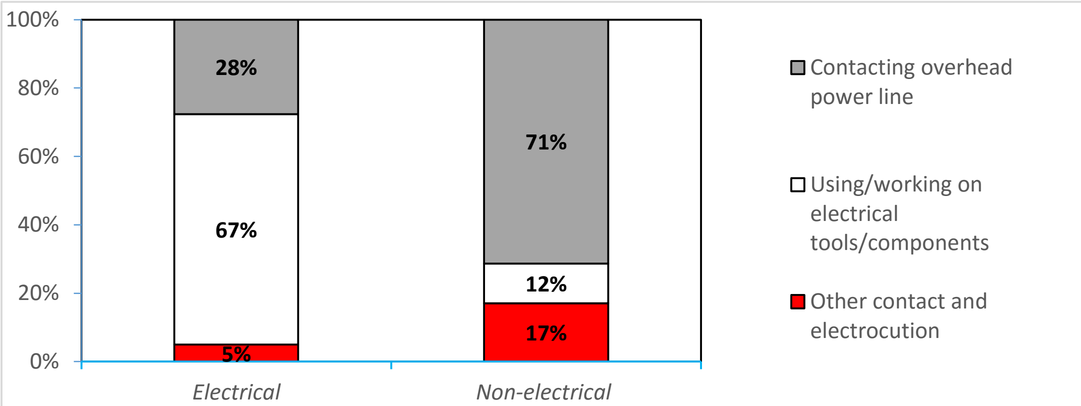
[13] The specialty trade contractors (STC) subsector comprises establishments whose primary activity is performing specific activities (e.g., pouring concrete, site preparation, plumbing, painting, and electrical work) involved in building construction or other activities that are similar for all types of construction, but that are not responsible for the entire project (U.S. Census Bureau 2013).

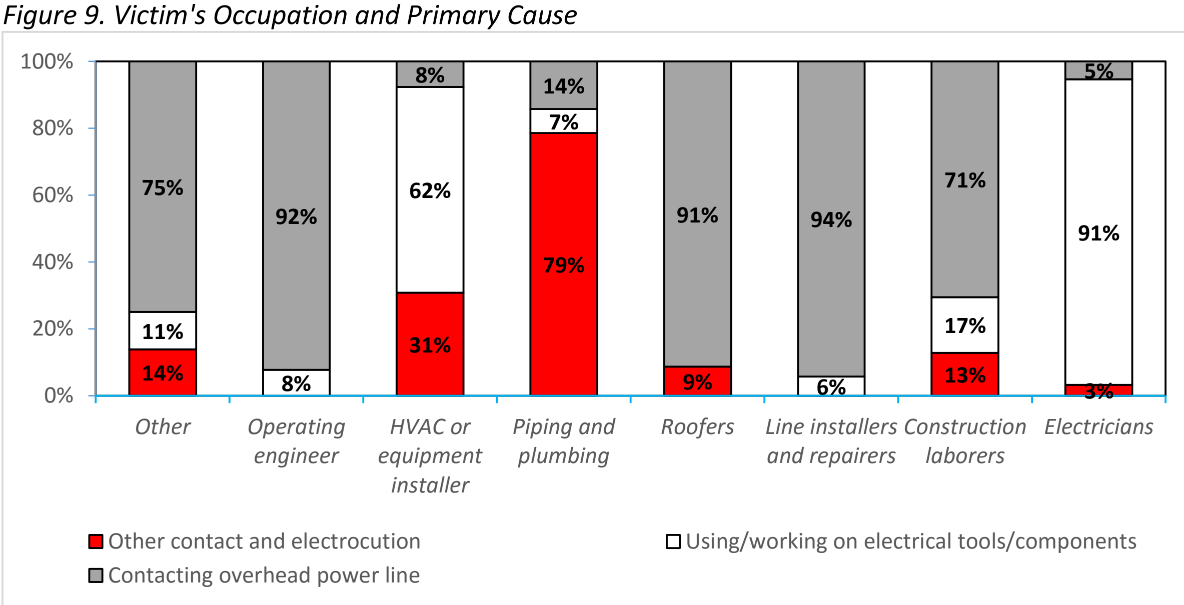
[14] For 3 victims, a work type could not be determined, therefore, it was coded as "Unknown".

Figure 8. Work Type among Primary Cause



As seen in Figure 9, the leading fatality cause among electricians and HVAC workers or equipment installers was Using/working on electrical tools/components. [15,16] At least 70% of the fatalities for all other occupations (except Piping and plumbing) resulted from Contacting overhead power line.

Figure 9. Victim's Occupation and Primary Cause



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[15] 'Other' consists of occupational groups which accounted for less than 4% of fatal events individually. These occupational groups were: (1) Carpenters, drywall and glazers; (2) Painters; (3) Masonry workers; (4) Steel workers and welders. Collectively, these occupational groups accounted for approximately 12% of fatal events in the current study.

[16] Other contact and electrocution was not a primary cause for operating engineers.

Statistical Results – Primary Cause Analysis

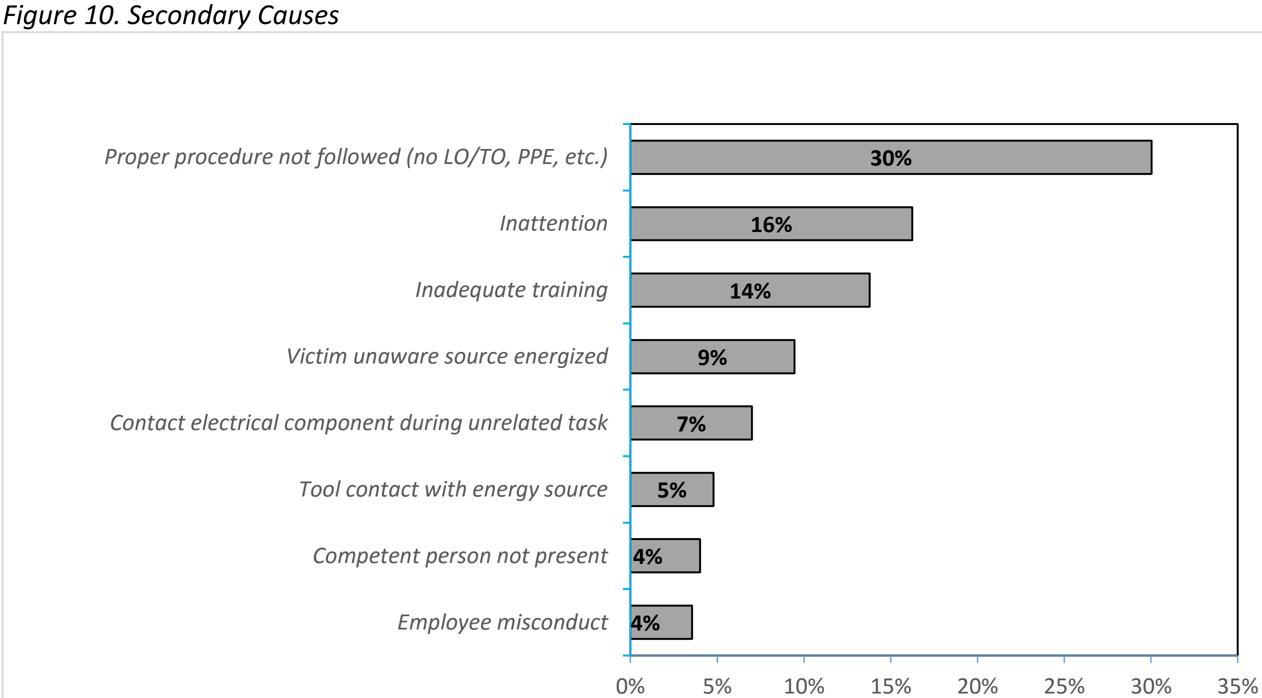
The strength of associations among Primary cause and the incident features discussed above were revealed through chi-square (χ^2) tests. The chi-square tests indicated significant associations between Primary cause and the incident factors of Employer's industry, Work type and Victim's occupation but not Victim's age. Primary cause represents the direct cause of a fatal event and not an event's contributing causes. It is useful to expand the analysis to include Secondary causes.

Analysis of Secondary Causes

Overview

The analysis of Secondary causes seeks to highlight the nature of fatal electrical events and supplement the associations seen in the analysis of Primary cause. The percentages of the eight leading contributing factors can be seen in Figure 10. Analysis will focus on these top eight secondary causes, which accounted for 89% of overall secondary causes. Proper procedure not followed was the leading secondary cause each year, while Inattention and Inadequate training were ranked second or third from 2005 to 2012. These top three contributing factors accounted for 60% of the contributing factors.

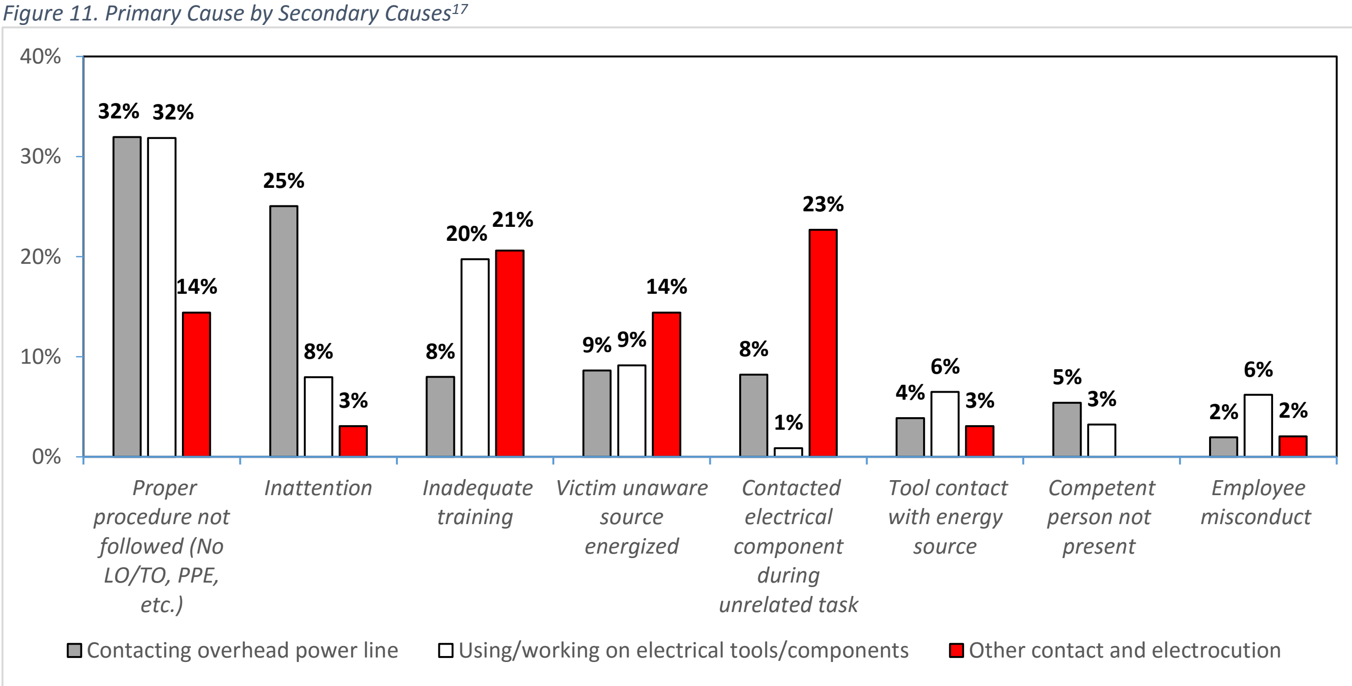
Figure 10. Secondary Causes



Frequency Distributions

Relative frequencies for each primary cause among the secondary causes are shown in Figure 11. Differences in the distribution of primary causes among secondary causes, and other frequency distributions, will be investigated further as Secondary causes are broken down by the incident factors.

Figure 11. Primary Cause by Secondary Causes[17]



Proper procedure not followed was the leading secondary cause for both Contacting overhead power line and Using/working on electrical tools/components contributing to 32% of these primary events. It was third for Other contact and electrocution (14%). The secondary cause, Inattention, contributed to 25% of the fatal events resulting from Contacting overhead power line, but was a contributing factor for only 8% and 3% of the electrical fatalities stemming from Using/working on electrical tools/components and Other contact and electrocution, respectively. Inadequate training was the second most frequent contributing factor for Using/working on Electrical tools/components (20%) and Other contact and electrocution (21%) and fifth for Contacting overhead power line (8%). Employee

[17] Competent person not present was not a contributing factor in events primarily caused by Other contact and electrocution.

misconduct only appeared in the top eight secondary causes for Using/working on electrical tools/components (6%). Secondary causes and incident factors were further analyzed to identify differences in contributing factors in electrical fatality events.

Relative frequencies for each secondary cause within the victims' age groups are shown in Table 4. For each age group, the top three secondary causes were as follows: (1) Proper procedure not followed; (2) Inattention; (3) Inadequate training. The breakdown of secondary causes by age group revealed proportions in agreement with the overall distribution of secondary causes; only negligible differences in contributing factors between age groups existed.

Table 4. Victim's Age by Secondary Causes

	Victim's Age						
Secondary Causes	*16-24* N (%)	*25-34* N (%)	*35-44* N (%)	*45-54* N (%)	*55+* N (%)	Unknown	**Row totals N (%)**
Proper procedure not followed (No LO/TO, PPE, etc.)	45 (29.6)	90 (29.1)	73 (31.3)	43 (30.9)	14 (29.8)	5 (26.3)	**270 (30.0)**
Inattention	25 (16.5)	48 (15.5)	40 (17.2)	22 (15.8)	9 (19.2)	2 (10.5)	**146 (16.2)**
Inadequate training	23 (15.1)	38 (12.3)	30 (12.9)	20 (14.4)	9 (19.2)	4 (21.0)	**124 (13.8)**
Victim unaware source energized	13 (8.6)	31 (10.0)	22 (9.4)	14 (10.1)	3 (6.4)	2 (10.5)	**85 (9.5)**
Contacted electrical component during unrelated task	11 (7.2)	22 (7.1)	16 (6.9)	9 (6.5)	3 (6.4)	2 (10.5)	**63 (7.0)**
Tool contact with energy source	6 (4.0)	16 (5.2)	9 (3.9)	8 (5.8)	3 (6.4)	1 (5.3)	**43 (4.8)**
Competent person not present	7 (4.6)	16 (5.2)	11 (4.7)	2 (1.4)	0 (0.0)	0 (0.0)	**36 (4.0)**
Employee misconduct	7 (4.6)	12 (4.0)	11 (4.7)	1 (0.7)	1 (2.1)	0 (0.0)	**32 (3.6)**
Other	15 (7.6)	36 (11.7)	21 (9.0)	20 (14.4)	5 (10.6)	3 (15.8)	**100 (11.1)**
Column totals N (%)	**152 (16.9)**	**309 (34.4)**	**233 (25.9)**	**139 (15.5)**	**47 (5.2)**	**19 (2.1)**	**899 (100)**

Analyzing secondary causes across Employer's industry revealed differences in the contributing factors as shown in Figure 12. Proper procedure not followed, was the leading secondary cause for all sub-sectors. The order of contributing factors across industries is essentially the same as shown in Figure 10.

Figure 12. Employer's Industry by Secondary Cause

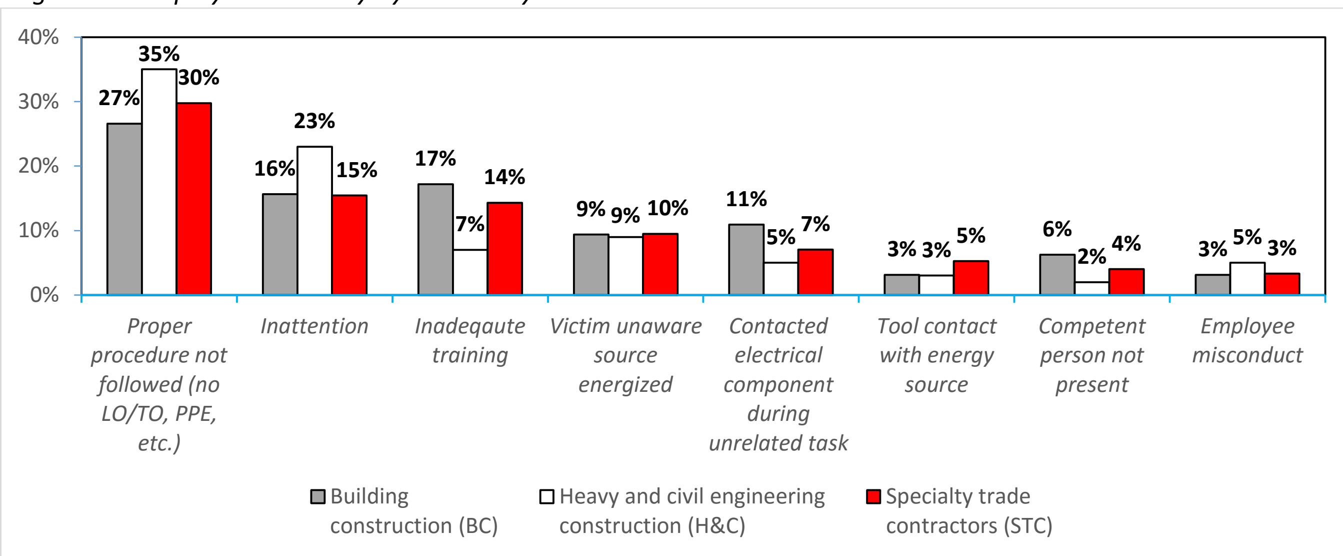
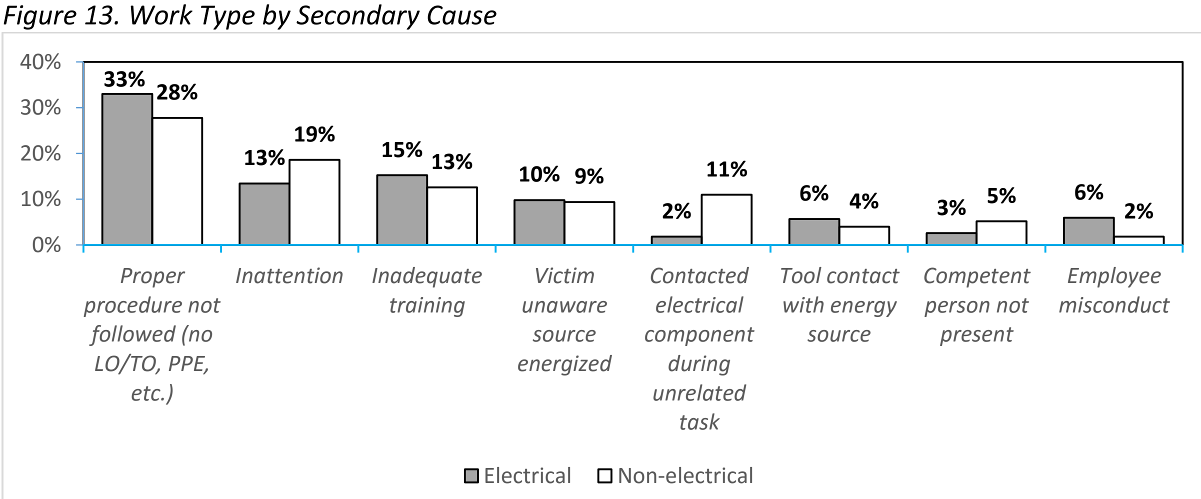


Figure 13 displays the distribution of Work type (electrical or non-electrical) among the top eight secondary causes examined. The frequencies indicate that electrical workers fail to follow proper procedure more often than non-electrical workers and Inattention makes a larger contribution to the fatalities of non-electrical workers (19%) than to electrical workers (13%).

Figure 13. Work Type by Secondary Cause



To further our analysis, Secondary cause was also analyzed across Victim's occupation (see Table 5). Proper procedure not followed was again the leading contributing factor across all occupations and was involved in 30% of fatalities.

Table 5. Victim's Occupation by Secondary Causes

	Victim's Occupation								
Secondary Causes	*Op. engineer* N (%)	*HVAC or equipment installer* N (%)	*Piping and plumbing* N (%)	*Roofers* N (%)	*Line installers and repairers* N (%)	*Laborers* N (%)	*Electricians* N (%)	*Other and unknown* N (%)	**Row totals N (%)**
Proper procedure not followed (No LO/TO, PPE, etc.)	12 (25.0)	8 (23.5)	8 (20.0)	20 (29.4)	32 (38.1)	68 (29.2)	88 (35.3)	34 (23.8)	**270 (30.0)**
Inattention	12 (25.0)	2 (5.9)	1 (2.5)	15 (22.1)	24 (28.6)	43 (18.5)	26 (10.4)	23 (16.1)	**146 (16.2)**
Inadequate training	2 (4.2)	8 (23.5)	6 (15.0)	6 (8.8)	3 (3.6)	31 (13.3)	48 (19.3)	20 (14.0)	**124 (13.8)**
Victim unaware source energized	5 (10.4)	7 (20.6)	7 (17.5)	6 (8.8)	7 (8.3)	23 (9.9)	24 (9.6)	6 (4.2)	**85 (9.5)**
Contacted electrical component during unrelated task	2 (4.2)	2 (5.9)	8 (20.0)	6 (8.8)	1 (1.2)	25 (10.7)	4 (1.6)	15 (10.5)	**63 (7.0)**
Tool contact with energy source	0	2 (5.9)	1 (2.5)	3 (4.4)	2 (2.4)	10 (4.3)	18 (7.2)	7 (4.9)	**43 (4.8)**
Competent person not present	0	1 (2.9)	1 (2.5)	4 (5.9)	3 (3.6)	16 (6.9)	6 (2.4)	5 (3.5)	**36 (4.0)**
Employee misconduct	0	0	0	0	5 (6.0)	7 (3.0)	18 (7.2)	2 (1.4)	**32 (3.6)**
Other	15 (31.2)	4 (11.8)	8 (20.0)	8 (11.8)	7 (18.3)	10 (4.3)	17 (6.8)	31 (31.7)	**100 (11.1)**
Column totals N (%)	**48 (5.4)**	**34 (3.8)**	**40 (4.4)**	**68 (7.6)**	**84 (9.3)**	**233 (25.9)**	**249 (27.7)**	**143 (15.9)**	**899 (100)**

Statistical Results – Secondary Cause Analysis

Associations among Secondary causes and Primary cause, along with the incident factors, were assessed by chi-square tests. The results indicated significant relationships between Secondary causes and Primary cause, Work type and Victim's occupation.

Analysis of Employers' Safety and Health Programs

Employer Overview

Information about victims' employers is presented in Figures 14 and 15**.** Figure 14 gives the distribution of employer type by employment size. It shows that 48% of firms in building construction employed 5 or fewer workers. In specialty trades 54% of the contractors employed 10 or fewer workers. Heavy and civil engineering construction firms were more evenly distributed in firm size: 48% employed 50 or fewer workers, and 53% employed 51 or more workers.

Figure 14. Employer Type by Firm Size

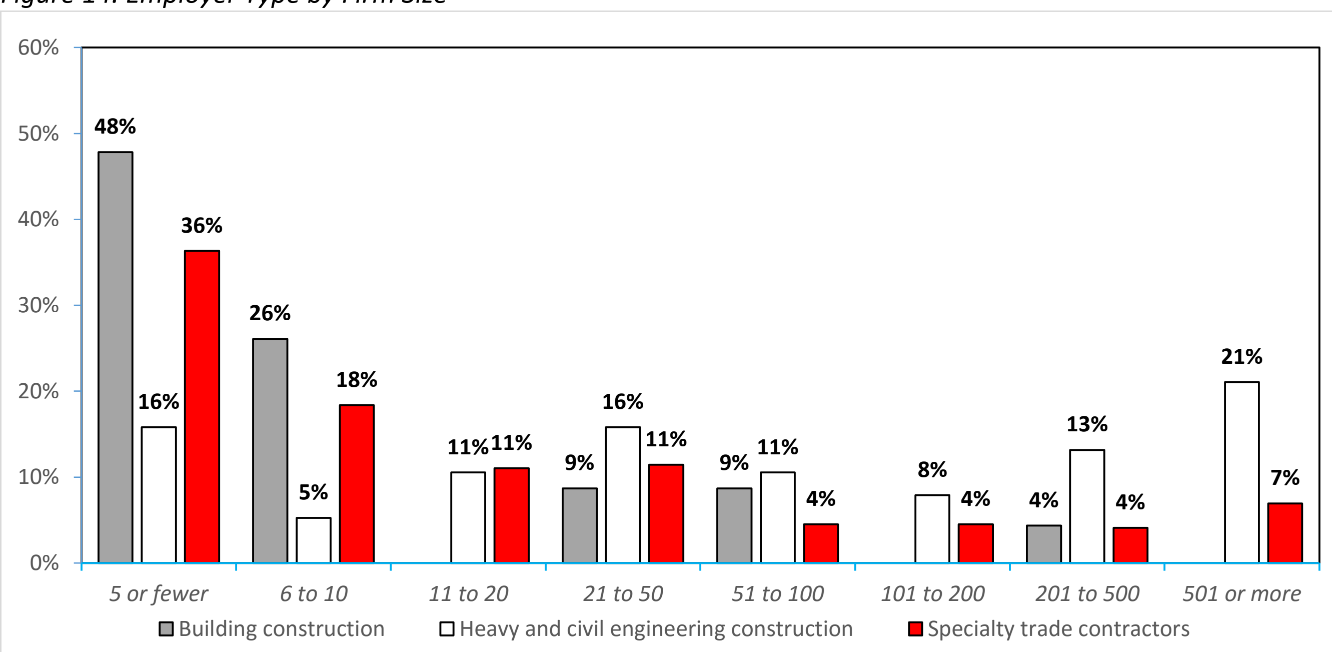
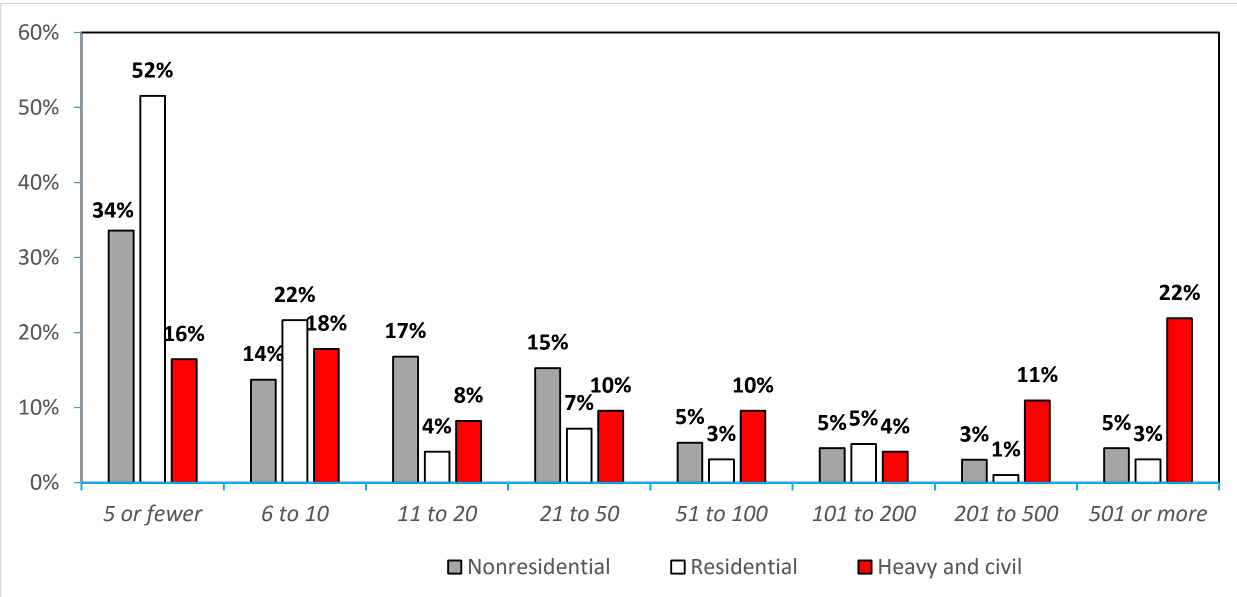


Figure 15 provides a distribution of construction project end use by firm size. The firm size frequency distribution for heavy and civil construction projects was roughly even: 52% of these projects employed 50 or fewer workers, while 47% employed 51 or more. Figure 15 also shows that firms engaged in either residential or nonresidential projects were of smaller size relative to firms working on heavy and civil construction projects: 52% of residential projects involved 5 or fewer employees, while 48% of nonresidential projects employed 10 or fewer workers.

Figure 15. Project Type by Firm Size



Statistical Results – Employer Characteristics Analysis

Chi-square tests were performed for Employer's industry and Project type by Firm size. Results indicated significant associations between Employer's industry and Firm size as well as Project type and Firm size.

Safety and Health Program Overview

The safety and health program components of interest are presented in Figures 16 and 17. Figure 16 reveals that more than 60% of employers had no written safety policy or a safety training program, and those with programs did not enforce them. It should be noted that the employers referred to here are those who experienced a fatality during the study period.

Figure 16. Employers' Safety and Health Program Components

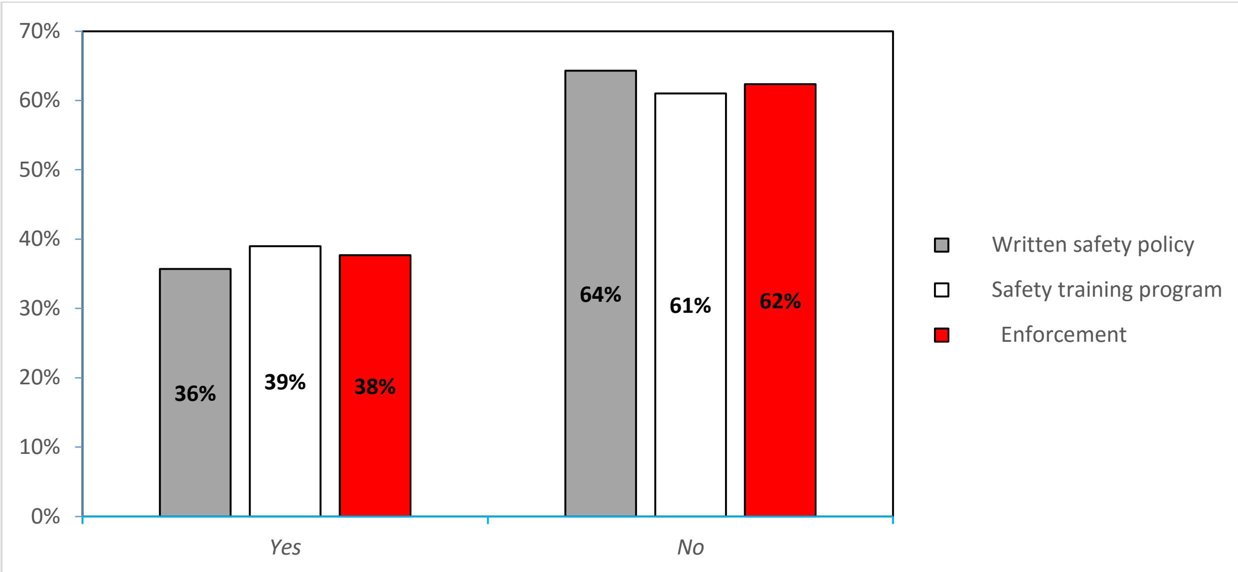
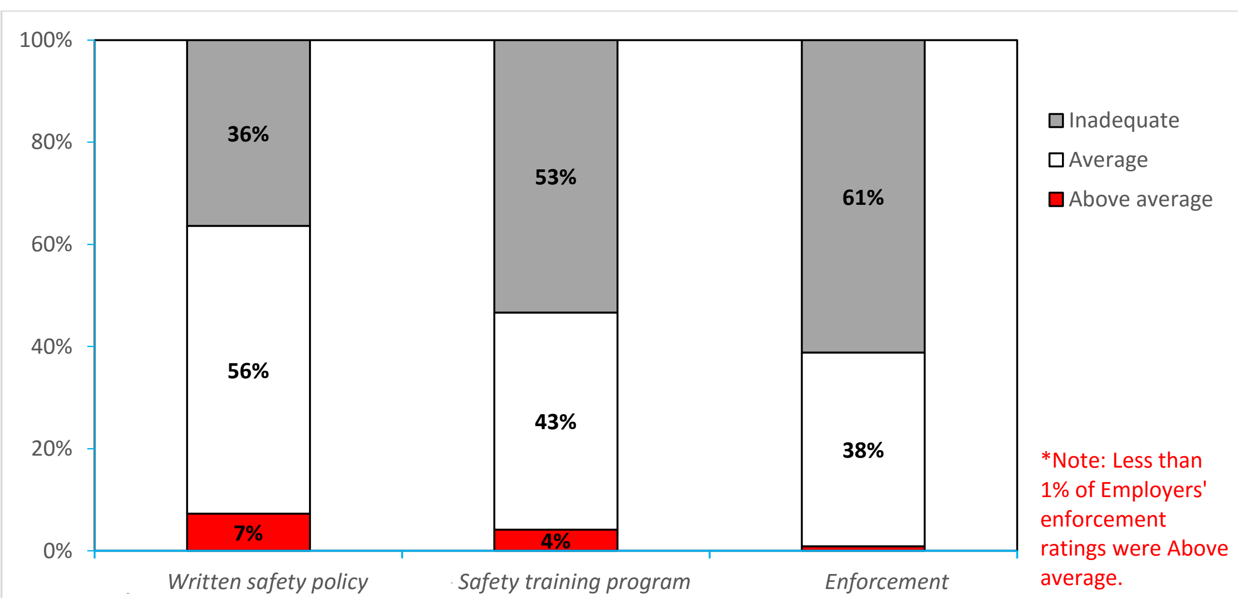


Figure 17 relates only to the minority of firms recorded as responding positively in Figure 16. Among these firms, Written safety policy as rated by CSHO's was most frequently rated as average, while the majority of both Safety training programs (53%) and Enforcement (61%) were rated as inadequate.

Figure 17. Employers' Safety and Health Program Component Ratings



Statistical Results – Safety and Health Program Analysis

Chi-square analysis between the presence of a Written safety policy and a Safety training program indicated a strong association. Chi-square tests were also conducted between Employer's industry, Project type and employers' safety and health program components. Results indicated significant associations between Project type and each of the safety and health program components. No significant relationships were found between Secondary causes and Written safety policy, Safety training programs and Enforcement.

Statistical Results – Contributing Factor Analysis

Analysis of contributing factors revealed potential areas of attention for improvements in workplace safety. The contributing factors analyzed were: (1) Proper procedure not followed; (2) Inattention; (3) Inadequate training; (4) Employee misconduct. Proper procedure not followed, Inattention and Employee misconduct were analyzed across Inadequate training to explore the effectiveness of current training regimes. Chi-square tests showed an overall significant relationship between Inattention and Inadequate training. All other tests provided insignificant results.

Standards Violated and Penalties Assessed

For the 305 fatal events examined in the current study, 859 citations were issued for violation of OSHA standards – an average of 2.82 citations per event. Table 6 shows the top ten standards violated by category. The violation of general safety requirements for electrical work was most frequently cited at 17%. The two general safety and health provisions were cited second most, and accounted for nearly 14% of the total citations when grouped. Violations relating to scaffolds and ladders were next in rank order of frequency, representing 5% and 3% of the total.

Table 6. Top 10 OSHA Standards Violated in Electrical Fatality Cases in Construction, 2005-2012

OSHA Standard Violated	Category	Final Penalties*	Number of citations	% of total citations
1926.416	Electrical – general requirements	$358,355	148	17.2
1926.21	General safety and health provisions – training	$88,950	64	7.5
1926.20	General safety and health provisions	$66,740	52	6.1
1926.451	Scaffolds – general requirements	$51,965	40	4.7
1926.1053	Ladders	$40,906	29	3.4
1910.1200	Hazard communication	$5,030	27	3.1
1910.333	Electrical – selection and use of work practices	$54,450	26	3.0
1904.39	Failure to report fatality, injury and illness information	$34,825	25	2.9
1926.950	Power Transmission and Distribution	$129,550	25	2.9
1926.550	Cranes and Derricks in Construction[18]	$46,600	21	2.4
	Subtotal	**$877,371**	**457**	**53.2**
Other		**$1,020,768**	**402**	**46.8**
Total		**$1,898,139**	**859**	**100**

*The initial penalty may be reduced through negotiation to reach the final penalty.

[18] OSHA standard 1926.550 was re-designated 1926.1501 by a new standard issued August 9, 2010, (Federal Register, 75 FR 48134.)

As noted in Table 6 the total final penalties assessed by OSHA during the period amounted to $1,898,139. Included in the total of 859 citations issued were 166 which carried a penalty of $0. As a result the average final penalty amounted to $2,739 for the 693 citations with a penalty, or $7,724 for each case. The initial penalty assigned in each case amounted to an average of $12,211, thus the final penalty per case was reduced by 36.7% from the average initial penalty. See Table 7.

Table 7. Distribution of Penalties Assessed

	N	Average	Median	Range	Total
Initial penalty	693	$4,330	$2,100	$0 – 70,000	$3,001,005
Final penalty	693	$2,739	$1,500	$0 – 70,000	$1,898,139

V. Discussion

Construction is a hazardous industry, and regularly represents disproportionate on-the-job fatalities relative to the private industry as a whole. Electrocutions are one of the 'Fatal Four' in construction and continue to pose a significant problem as OSHA seeks to reduce the risk of electrical events. This study added to the work done by Zhao et al. (Zhao et al., 2013), and focused on the characteristics surrounding electrical fatalities in construction. The analysis methods employed allowed the researchers to uncover areas of emphasis for improving on-the-job electrical safety. The dataset used was built from the narratives and coded data for OSHA case files compiled by CSHOs in the field. By extracting details of incident features, input data was compiled that was representative of the case file records. Analysis concentrated on: (1) Fatality cause(s) – Primary and Secondary; (2) Employers' Characteristics; (3) Employers' Safety and Health Programs; (4) Contributing factors to fatalities and (5) (OSHA) Standards Violated and Penalties Assessed.

The Data

The findings presented above can, to a great extent, be compared with the data assembled by Zhao et al. in order to provide a broad base from which to study the problem of electrocutions in the construction industry. Taken together these two studies encompass 448 fatal incidents (308 from this study; 140 from the Zhao study) spanning more than two decades (2005 – 2012 this study, 1989 – 2010 for the Zhao study) and are believed to comprise a unique reporting of detailed fatality case studies.

For the most part the data assembled by Zhao et al. and the findings of the current study are similar. For example, the analysis of the Employer's industry revealed differences in proportions among the three industries, but the rank order was the same in both studies.

In examining written safety policy and safety training programs the two studies reported similar results except that slightly fewer employers examined in the current study had either a written safety policy or a safety training program.[19] In terms of written safety policies only 36% of the cases in the current study reported such policies compared with 48% in the Zhao et al. study. For safety training programs the percentages were more nearly equal: 39% to 43% respectively.

In analyzing the data for Victim's occupation there was some variation in the two studies. In the current study electricians led all occupations at 30% with line installers and repairers at 11%. In the Zhao et al. study line installers and repairers amounted to/accounted for 24% with electricians at just 21%. Laborers amounted to 25% of the employees in both studies.

Examination of Victim's age by age grouping show that both studies represented similar populations. Not only were the frequency distributions similar, the average age of each study population was almost identical: 35 for the current study and 36 for the Zhao et al. study.

There was some variation in Project type between the two studies. While Residential building involved a similar percentage of project types in both studies (30/31%), the current study reflected greater coverage of Non-residential building at the expense of Heavy and civil construction whereas Zhao et al. was oriented toward Heavy and civil building at the expense of Non-residential building.

[19] In the current study all safety component entries reported as "Unknown" in the CSHO's report were coded as "No".

Despite this difference, however, both studies were in substantial agreement regarding electricity origin. Power lines accounted for 52% of the fatalities in the current study, followed by Transformers, Conductors, etc. (33%) and Tools, etc. (15%).[20]

One final area of commonality of the two studies is the role of Human error origin. In this study 82% of the events were attributed to the Victim with only 17% attributed to a third party. For Zhao et al. 89% of the events were traced to the Victim with 11% traced to a third party.[21]

Based on the summary presented above it is clear that there is a general level of agreement between the two studies discussed. The current study deals with a more recent, robust dataset, and includes additional factors for further analysis. The study published by Zhao et al. covered the years 1989 to 2010, in comparison, the current study deals with the period from 2005 to 2012 and consisted of data for 132 fatal events resulting in 140 fatalities; the current study's dataset consist of data for 305 fatal events accounting for 308 fatalities. While Zhao et al. performed an analysis of employers' safety and health programs, their analysis focused on the existence of these programs and not necessarily on an existing program's rating. CSHOs are required to rate employers' safety and health programs during fatality investigations, and the current study was able to use these reported ratings in its analysis of employers' safety and health programs. Information was also gathered from the case files regarding OSHA standards violated and the corresponding penalties for each of the 305 fatal electrical events.

Results and Recommendations

Differences in Fatality Causes

Primary

The current study's analysis of primary causes of electrical fatalities found that Contacting overhead power line accounted for 52% of electrical fatalities. More than half of the fatalities were in two

[20] In the Zhao et al. report these percentages are 53%, 26% and 21% respectively.
[21] The components of "Human error origin" were (1) Victim, (2) Other employee, (3) Combination, and (4) Wrong place at wrong time. (1) and (4) were combined to form 'Victim self' while (2) and (3) were combined to form 'Third party'.

categories: cranes, booms and lift equipment (32%) and direct contact by the victim (24%). These results are similar to those found by Cawley and Homce (Cawley, 2003), as well as Zhao et al. (Zhao et al., 2013). Beavers et al. (Beavers et al., 2006) found failure to maintain a safe distance from power lines to be a leading cause of crane-related fatalities, and both CIRPC (2009) and CPWR (2013) found that a body part contacting overhead power lines was a leading cause.

The primary electrical hazard for firms operating in heavy and civil construction is Contacting overhead power line, while for specialty trade contractors it is Using/working on electrical tools/components. Further analysis indicates significant differences in electrical hazards encountered in these industries. These differences suggest that electrical safety training programs should be tailored to the occupations and the industry of the employer.

Also, statistical analysis indicated that there are significant differences between the electrical hazards encountered by electrical and non-electrical workers, further reinforcing the notion that electrical safety training programs should be tailored to the occupations and the industry of the employer. Electrical workers most frequently encounter electrical hazards while Using/working on electrical tools/components while non-electrical workers most often encounter electrical hazards by Contacting overhead power lines which is similar to CPWR's 2013 finding. Appropriate measures and training should be taken to avoid or minimize these dangers, e.g. ensuring that electrical tools are in safe working condition, properly grounded and guarded circuits have been de-energized and locked out, and overhead power lines protected or marked.

Finally, there were significant associations between Contacting overhead power lines and the Victim's occupation for Laborers, Line installers and repairers, Roofers, Operating engineer and Other. Operating engineers typically contact overhead power lines through mobile equipment while for electricians it was Using/working on electrical tools/components. Fatalities resulting from Other contact and electrocution were primarily associated with piping and plumbing workers and HVAC or equipment installers.

In summary, results suggest that there are significant differences between the electrical hazards encountered among industries, types of work and occupations. These differences should be considered when establishing and evaluating safety and health programs.

Secondary

An analysis of contributing factors highlights the fact that most electrical incidents are preventable. The analysis of secondary causes found, Proper procedure not followed, Inattention and Inadequate training were the three leading contributing factors. These three contributing factors accounted for 60% of all contributing factors. The prevalence of these contributing factors suggests that they should be of particular interest to both employers and OSHA in developing and maintaining a safe work place.

Statistical analysis revealed significant relationships between Secondary causes and: Primary cause, Work type and Victim's occupation. Chi-square tests indicated that there are significant differences in the contributing factors for the three primary causes. Inattention was significantly associated with Contacting overhead power line. Inadequate training, Competent person not present and Employee misconduct were all significantly related to Using/working on electrical tools/components. Industries and occupations significantly affected by these primary causes should focus on reducing the contribution of these secondary causes.

Results show that electrical and non-electrical workers encounter different electrical hazards. Proper procedure not followed and Employee misconduct were significantly correlated with electrical workers, while Contacted electrical component during unrelated task was most often associated with non-electrical workers. This suggests that proper training and hazard awareness, along with enforcement of established procedures, is important for ensuring the safety of electrical workers. Also, different types of electrical safety training are needed among work types.

Analysis revealed significant differences in fatality contributing factors across construction industry occupations. Inadequate training and Employee misconduct were significantly related to electrician fatalities. These associations imply that satisfactory training and understanding of electrical hazards is needed in the electrician trade. Inattention was associated with operating engineers and line installers and repairers, indicating that worker attentiveness should be practiced at all times while on-the-job. Victim unaware source energized was correlated with HVAC or equipment installers and piping and plumbing workers, while Contacted electrical component during unrelated task was correlated with piping and plumbing workers and laborers. Again, results show that hazard awareness and worker attentiveness are essential in mitigating electrical fatalities

There are significant differences in the factors contributing to the occurrence of the primary fatal events covered in the current study, and contributing factors differ significantly between electrical and non-electrical workers. Coupled with the findings of the analysis of primary causes, there is a clear need for different types of electrical safety training across industries and occupations. For the training of electrical workers, the NIOSH publication titled “Electrical Safety: Safety and Health for Electrical Trades” (Student Manual) may be of great benefit to employers (NIOSH, 2009). A broad-based educational initiative on electrical hazards in construction, along with adoption of the previously mentioned manual may have the largest impact in reducing the most important fatality secondary causes, Proper procedure not followed, Inattention, Inadequate training and Employee misconduct.

Safety and Health Program

More than 60% of employers had no minimum safety standards and 60% of those with minimum standards failed to enforce their policies and programs. It is concerning to see this lack of safety and health programs and enforcement as these are explicitly required by OSHA. A number of reasons why this may occur have been offered by others such as the cost of establishing and maintaining mandatory safety programs and potential reduction in productivity. However, these additional costs are unlikely to outweigh the direct and indirect costs of not having safety programs. Occupational injuries and illnesses can result in direct costs related to workers' compensation, medical bills and legal services. Indirect costs can also arise, including new employee training, decreased productivity, accident investigation costs, OSHA penalties and lowered employee morale. By investing in effective safety and health programs, employers can expect to reduce these costs, and generate improved productivity and financial performance (ASSE, 2002). The following resources may be of use to employers seeking to learn more about safety and health management and in establishing their own programs:

https://www.osha.gov/dcsp/compliance_assistance/sampleprograms.html (Sample safety programs, by topic)

https://www.osha.gov/SLTC/etools/safetyhealth/index.html (OSHAs Safety and Health Management Systems eTool)

OSHA rates safety and health programs components on a scale that ranges from zero to one. Our data set allowed us to calculate the average ratings for the following program components: Written safety policy, 0.59, Safety training program, 0.61 and Enforcement, 0.53. As is obvious from these data safety programs are woefully inadequate, at least for the group of employers studied.

Chi-square test of fatalities indicated significant associations between Project type and each of the above safety and health program components. Zhao et al. (Zhao et al., 2013) explored the impact of safety training on other electrocution features and found an overall significant relationship between safety training programs and construction project type. Standardized residuals showed a significant relationship between fatalities and the absence of each of the safety and health program components on Residential construction projects. Residual analysis also showed a significant association between the presence of written safety policies and heavy and civil construction projects. These results suggest that firms engaged in residential projects, which are typically of smaller size relative to firms engaged in other projects, should focus on establishing safety and health programs.

Secondary causes are not significantly related to the existence of a safety and health program nor to the ratings of selected components – written safety policy, safety training program and enforcement. The implication is current safety and health policies and programs are not sufficient for mitigating the occurrence of fatal electrical events. The efficacy of existing safety and health programs needs to be reexamined and improved since most electrical fatalities are preventable.

Contributing Factors

The contributing factors Proper procedure not followed, Inattention and Employee misconduct were analyzed across Inadequate training to investigate the impact of current training regimes. The relationship between Proper procedure not followed by Inadequate training proved to be insignificant as did Employee misconduct by Inadequate training. This suggests that current safety and health training programs have little effect on following proper procedures or reducing employee misconduct.

Standards Violated and Penalties Assessed

OSHA standards related to general safety requirements for electrical work and general safety and health provisions were most frequently cited. This is not surprising given that previous results have shown that the majority of firms analyzed did not possess safety programs, and that the quality of currently established training and safety and health programs was insufficient for reducing fatalities.

Financial penalties were analyzed and given the value of the final penalties it seems unlikely these fines will change employer behavior because employers perceive likelihood of a job fatality as low and the penalties assessed for a fatality in the industry likely unknown (Moore et al., 2014). Even if these penalty amounts, which vary from fatality to fatality, were known, the current study's calculated average penalty of $7,724 per case is unlikely to outweigh an employer's perceived loss of productivity. Increasing the financial penalties and publicizing this information may make employers more responsive to employee safety. In the long-term, this policy could push out smaller firms, and leave larger, better financed companies who are willing and able to resolve safety issues in the face of higher penalties (Moore et al., 2014).

Limitations

Data Issues

While the researchers received the majority of case files in the years covered by the current study (2005 to 2012), in 2008 and 2012, less than 20% of fatality reports completed by OSHA were received. Greater access to case files during those years would improve the representativeness of results. Also, for the period covered, there was a considerable decline in construction activity. Construction employment fell by 28% from the peak in 2006 to a low in 2011. This decline could skew an analysis of fatality causes, although, as the current results agreed with those of the work done by Zhao et al., covering a longer period, this bias is seemingly minimized.

Many investigation files recorded the status of safety and health programs as “Unknown”. It was assumed that entries reported as “Unknown” implied that an employer did not possess the respective safety program component(s). Also, because only 14 individual safety and health components were rated as above average, this rating category was not used in the current study’s safety analysis. A more comprehensive dataset would improve the accuracy and reliability of safety analysis estimates. As discussed in Data and Methods, case files’ coded data and narrative descriptions did not always agree. To address these issues, Beavers et al. (Beavers et al., 2006) offer several recommendations for improving OSHA data. These suggestions, if adopted, could help future researchers minimize the above limitations and are summarized as follows: (1) A quality control system to ensure consistent and accurate coding and fatality data entry into the OSHA Information System (OIS); (2) Formal guidance and standardization of CSHOs narrative descriptions; (3) Increased scope of data collection to not only justify the violations cited, but to also include comprehensive information for use in intervention strategy development.

All elements of secondary causes were not included in our statistical analysis due to low or nonexistent cell counts. The relationships shown may become stronger or weaker with a more complete dataset. Inclusion of all sixteen secondary causes could result in significant relationships purely by chance due to increased contingency table size, but failure to include all sixteen secondary factors is not believed to be a major limitation since the top eight included 89% of the observed secondary causes.

Analysis Issues

The current study focuses on the proportional magnitude of problems faced in the construction industry regarding electrocution hazards, and these proportions do not capture the risk a worker is exposed to while on-the-job. Future studies should also incorporate analyses of electrical fatality rates to better assess the risk of electrical death faced by construction workers.

VI. Conclusion

Despite OSHAs comprehensive safety standards and recommendations from previous research, the construction industry continues to account for a disproportionate share of occupational injuries. Within the industry, electrocutions are one of the primary hazards faced. From 2005 to 2012, electrical fatalities in construction represented 47% of total private industry electrocutions. The dataset for the current study comes from a detailed analysis of 305 fatality case files compiled by CSHOs for OSHA during the period 2005 to 2012. The objective of this study was to examine the features of electrical accidents and reveal the most common electrical safety challenges on-the-job so that management may optimally allocate their safety resources.

Contacting overhead power lines continues to be the primary electrical danger in construction, while Proper procedure not followed, Inattention and Inadequate training are the key contributing factors for electrical fatalities. These causes should be the focus in developing safety and training programs.

Proper electrical safety training, educational initiatives in electrical hazard awareness and enforcement of safe work methods are all integral for reducing electrocutions in construction. While general electrical safety training is necessary, and especially important for unskilled workers (particularly power line safety), different forms of training are needed across industries, work types and occupations. Training programs' effectiveness should be regularly examined, and employee training should be recurrent.

In examining both the primary and secondary causes of electrocutions, it is apparent that reductions in electrical events depend upon both employers and employees. Many contributing factors relate to victim conduct, yet it is also true that inadequate training and enforcement failures are the fault of employers.

The absence of safety and health programs and inadequacy of existing plans is particularly concerning. Perhaps further publicizing the positive returns a safety and health program can yield may be the best option for motivating the formation of safety programs and enhancing current plans. In creating or improving safety and health programs, OSHA should focus its resources on employers by size, industry characteristics and types of projects.

Based on the authors' calculation of the average penalty per citation, current OSHA fines are unlikely to encourage employers to establish safety programs or enhance existing programs. Significantly higher financial penalties and educational and training initiatives are viable options for reducing fatalities, and improvements in the quality of safety and health programs would likely lead to reductions in financial penalties faced by firms.

Acknowledgements

The underlying fatality data for this study was compiled from case files constructed in the field by CSHOs from OSHA. The views expressed in this study do not necessarily reflect the views of OSHA.

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