Trends of Occupational Fatal and Nonfatal Injuries in the Electrical and Mechanical Specialty Contracting Sectors: The Necessity for a Learning Investigation System

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Abstract

The specialty electrical and mechanical contracting sectors provide crucial services and perform functions that are vital to the products delivered by the construction industry. The main purpose of this study is to investigate the causes of fatal and nonfatal injuries in these specialty construction sectors over time as well as their effects on the level of safety performance in the industry. Accordingly, the most prevalent causes of fatal and nonfatal incidents in the mechanical and electrical sectors are investigated and presented as a longitudinal study from 2005 to 2015. The trends in occupational injuries in these sectors over this period of time are also compared to the trends reported in previous studies. The results from this study show that the direct causes of fatal and nonfatal injuries in the electrical and mechanical fatal and nonfatal injuries differ from those found in the construction industry in general. However, the electrical and mechanical construction industry trends identified in this study are similar to previously reported trends. The similarities between the current findings and those of previous studies highlight real shortcomings in the safety management approaches within the construction industry. Based on the findings of this study, a learning investigation system has been proposed to improve safety performance among electrical and mechanical specialty contractors.

Introduction

The construction industry spans a wide variety of disciplines and trades and is categorized by the Bureau of Labor Statistics (BLS) into three sectors, namely (1) building construction, (2) heavy and civil engineering construction, and (3) specialty trade construction (Shrestha et al., 2016). Specialty trade construction include electrical and mechanical contract work. According to Robinson et al. (1999), there are two categories within the electrical contracting sector: (1) outdoor work, including high-voltage wiring that connects community substations to consumers, and (2) indoor work comprising wiring of interior circuitry. Electrical contractors are mainly responsible for the installation and maintenance of electrical systems (Abudayyeh et al., 2003). Based on the BLS, there were about 715,400 electricians in the United States in 2018, with roughly 500,000 working in the construction industry (USDOL, 2018a). On the other hand, the mechanical sector is primarily concerned with the installation and maintenance of mechanical systems (Fredericks et al., 2002). The US Department of Labor (USDOL, 2018b) classifies mechanical contractors into two trade groups: (1) plumbers and pipefitters that handle sanitary drainage, potable water, storm drains, gas supply systems and gas distribution systems as well as pipefitters that place and repair heating, cooling, and energy distribution systems (Fredericks et al., 2002), and (2) sheet metal workers and duct installers that place and maintain the sheet metal products that make up the elements of heating, air conditioning, and ventilation systems. Sheet metal workers also make and repair drainage and roofing products. According to the BLS, there were about 500,300 plumbers and pipefitters in the United States in 2018, with more than 350,000 working in the construction industry (USDOL, 2018b).

The construction industry is generally known for its poor safety performance record (Al-Bayati et al., 2019). In 2018, it experienced the highest count of electrical fatalities, with a rate of 0.80 fatal incidents in 100,000 workers (ESFI, 2018). OSHA also identifies electrocution as one of the four most common causes of fatal occupational injury in construction (USDOL, 2018c). Many factors have been assessed to identify the causes of incidents in the electrical and mechanical sectors, including the type of project, project end-use, project cost, and task attributes (Gholizadeh and Esmaeili, 2016; Hinze, 1997; Shrestha et al., 2016). The rate of electrical fatalities was significantly higher for new projects and maintenance projects (Gholizadeh and Esmaeili, 2016). Additionally, Shrestha et al. (2016) found that the injury rates of larger firms (in terms of annual revenue and number of employees) were significantly lower than those of smaller ones. Abudayyeh et al. (2003) and Frederick et al. (2002) investigated hazardous tasks and tools associated with the causes of illnesses, injuries, and fatalities in the mechanical and electrical contracting sectors. The back, fingers, and hands were found to be the most commonly injured parts of the body among mechanical and electrical construction workers. Umar et al. (2018) noted that the back of the body is among the top most frequently reported injury areas among general construction workers. The key areas of the body in which pain was reported in this study include the back (39.40%), knees (18.11%), shoulders (15.3%), legs (14.52%), and neck (12.37%). Fredricks et al. (2002) and Abudayyeh et al. (2003) administered surveys to reveal the most common tasks contributing to back, finger, and hand injuries (see Table 1) and recommended that more attention should be paid to these tasks. This attention could include training, supervision, and detailed job safety analysis.

Insert Table 1

Goal and Objectives

This study aims to investigate the current trends of fatal and nonfatal injuries in the mechanical and electrical construction sectors within the United States and to compare findings with earlier trends as reported by Abudayyeh et al. (2003) and Frederick et al. (2002). To achieve this goal, the following objectives have been pursued:

1. Analyze occupational injury, illness, and fatality trends in the mechanical and electrical construction industry between 2005 and 2015 using BLS data.
2. Compare current trends with the earlier studies by Abudayyeh et al. (2003) and Frederick et al. (2002) to identify changes over time.

Methodology

The BLS's fatal and nonfatal injury statistics were collected from 2005 to 2015. Figure 1 illustrates the research methodology that was followed in this study. The investigation utilizes the work-related injuries and illnesses data as categorized by the BLS's Occupational Injury and Illness Classification System (OIICS) (BLS, 2020a). The system uses two characteristic codes (i.e., "Nature" and "Part of Body Affected"") and two circumstance codes (i.e., "Source of Injury or

Illness” and “Event or Exposure”) for injuries. Table 2 below illustrates the OIICS’s coding system.

Insert Figure 1

Insert Table 2

On the other hand, fatal injuries are categorized according to their direct cause as follows (BLS 2020b):

- Violent injuries by persons or animals.
- Transportation incidents involving transportation vehicles or powered industrial vehicles in normal operation or in a collision.
- Fires and explosions in which a person fell or jumped from a burning building, inhaled a harmful substance, or was struck by or against an object as a result of an explosion or fire.
- Falls, slips, and trips, including falls on the same level, falls and jumps to lower levels, falls and jumps curtailed by a personal arrest device, and slips and trips that did not result in a fall.
- Exposure to harmful substances or conditions in the work environment, including electricity, radiation, noise, and temperature extremes.
- Contact with equipment or objects, including fatal injuries resulting from being struck by equipment or objects, being struck against equipment or objects, or being caught in or compressed by equipment or objects.

- Overexertion and bodily reactions, including fatal injuries resulting from free bodily motion, excessive physical effort, repetition of bodily motion, the assumption of an unnatural position, or remaining in the same position over an extended period.

Findings

The fatal and nonfatal injury trends for electricians and mechanical construction workers were collected from 2005 to 2015. The nonfatal injury trends will be presented based on the OIICS coding system outlined in Table 2. The most common nonfatal injuries in the electrical and mechanical construction industries were sprains and strains, which accounted for 34.6% and 34.2% of the total cases, respectively. Cuts and punctures were the second most prevalent injuries, followed by fractures and back pain (see Figure 2). As for the parts of the body affected, the back was the most frequently affected, accounting for 21% and 19.9% of all electrical and mechanical injuries, respectively. The fingers were the second most frequently affected, followed by hands and knees (see Figure 3).

The most common sources of electrical and mechanical injuries were parts and materials, accounting for 23% of electrical injuries and 23.9% of mechanical injuries. Floors, walkways, and ground surfaces were the second most common sources, followed by worker motions, worker positions, and hand tools (see Figure 4). Contact with objects was found to be the most common event or exposure resulting in injury, accounting for 32.9% of electrical injuries and 37.1% of mechanical injuries. The second most common event or exposure resulting in injury was overexertion, followed by all types of falls and transportation injuries (see Figure 5). The overall trends seem to be consistent with those in the construction industry, shown as “Others” in Figures 1 through 5.

Insert Figure 2

Insert Figure 3

Insert Figure 4

Insert Figure 5

On the other hand, there are a few notable differences in the trends of fatal injuries. Fall-related fatal injuries seem to be rarer among electrical and mechanical contractors than among other construction professionals. In addition, electricians seem to face higher numbers of fatalities from harmful substances or environments. This is understandable because electric shock (e.g., arc flashes) and electrocution (e.g., touching a live wire) fall under this categorization (see Figure 6). In addition, mechanical workers seem to face a higher rate of fatalities due to being struck by or caught by an object. Finally, the higher rate of assaults and violent acts in mechanical construction requires further investigation.

The trends in fatal injuries between 2005 and 2015 are presented in Figure 7, which reflects a reduction in the number of fatalities in electrical construction and a relatively stable number of fatalities in mechanical construction. Table 3 shows the averages of the total numbers of fatal and nonfatal injuries that have been analyzed in this study.

Insert Table 3

Insert Figure 6

Insert Figure 7

A Comparison with Previously Reported Trends

The trends in nonfatal injury found in this study seem to be consistent with the trends previously reported by Abudayyeh et al. (2003) and Fredericks et al. (2002). As for affected body parts, there is a limited ability to objectively compare trends because the BLS utilized a different categorization system for this section (see Figure 8). Table 4 illustrates the consistency in the trends of the nature of nonfatal injuries reported in this study and the trends previously reported. The only noticeable difference is a slight reduction in sprains and strains and an increase in pain injuries. The data suggests a consistency between the previously reported trends and the trends identified in this study regarding injury sources. Table 5 shows a comparison between injury trends based on injury sources. Finally, the current trends in the primary event or exposure are also similar to those reported earlier. As shown in Table 6, the rates of fall and transportation incidents have slightly increased.

The comparison of the fatal injury trends identified in this study with those reported earlier suggests a clear increase in the rate of assaults and violent acts (see Table 7). The data also indicates an increase in fall incidents among mechanical workers. On the other hand, there has been a reduction in transportation incidents. In addition, incidents due to harmful substances or conditions (e.g., electrocution and temperature extremes) are still more common among electricians than among mechanical workers. Finally, fire and explosion incidents have also increased, especially among mechanical workers (See Table 7).

Insert Figure 8

Insert Table 4

Insert Table 5

Insert Table 6

Insert Table 7

Discussion and Recommendations

There has been a great reduction in the number of deaths caused by workplace accidents, although the number is still quite alarming (Hinze et al., 2013). It is vital to know the causes of workplace incidents because this knowledge guides the development of strategies to avoid similar incidents in future projects (Al-Bayati and York, 2018). Identifying the tasks that are frequently associated with injuries, illnesses, and/or fatalities is essential to managing safety on construction sites. The findings of this study show that the direct causes of fatal and nonfatal injuries in electrical and mechanical construction differ from those in the construction industry in general. Thus, the proposed safety programs and risk mitigation efforts should be tailored to this difference. Harmful substances or environments seem to be the main causes of fatal injuries among electricians (see Figure 5). On the other hand, in mechanical construction, fatal injuries seem to be evenly distributed in terms of their direct causes, except for injuries caused by fire and explosions, which are slightly more common.

The most concerning findings of this study are the similarities between some of the identified direct causes and those reported by Abudayyeh et al. (2003) and Fredericks et al. (2002). These similarities suggest that the construction industry has not fully learned from previous incidents to improve overall safety performance. This observation could be explained by the following:

1. The excessive reliance on lagging indicators rather than leading indicators could be the reason. Lagging indicators depict historical information about changes in construction safety performance, but they give no information about why these changes occurred, nor

do they provide further insights into the existing safety conditions, as suggested by Hinze et al. (2013), who stated that these indicators have reached a point of diminishing returns and should be replaced by leading indicators. As a result, safety improvements are declining considerably, as noted by Hinze et al. (2013). The call to utilize leading indicators will help the industry predict future safety performance and control the identified hazards. Thus, the industry should focus on leading indicators to overcome the current challenges, especially serious ones.

2. Serious incidents could be prevented by improved approaches to learning from previous experiences (Cooke and Rohleder, 2006). It is unfeasible to effectively address incidents that have not been comprehensively studied (Lundberg et al., 2009). The fact that electrical and mechanical contractors continue to suffer serious injuries from the same direct causes is a wake-up call that should be addressed by the industry. It seems that the industry is not fully utilizing incident investigation as a valuable source of learning.

The repetition of the same direct causes in the Australian construction industry has been noted by Dohshon and Hassall (2016), who have concluded that the industry has failed to address the repeat incidents challenge. The fact that workers are injured by the same direct causes has previously been discussed by Kertz (2009). However, few, if any, studies highlight the repetition in the direct causes of fatal and nonfatal construction injuries in the United States. Repeat injuries should not be viewed as a normal process of body mechanisms that normally fail from time to time. Kletz (1993) argued that the repetition in the direct causes of incidents could be due to a failure to extract lessons from safety incidents. This suggests that the construction industry lacks a comprehensive investigation and learning system. For example, Al-Bayati and York (2019) suggest that the current incident investigation reports provided by the National Institute of Occupational Safety and Health (NIOSH) only delivered the direct cause (i.e., the tip of the iceberg), meaning that the industry is losing vital learning opportunities. To be useful, an incident investigation must deliver an assessment of hazard control effectiveness and translate this into recommendations and training materials which, in turn, will lead to a reduction in future similar incidents (Dohshon and Hassall, 2016). Incidents should be considered a quality problem that must be controlled to avoid occupational risks (Cooke and Rohleder, 2006). As a result, firms should utilize an incident learning system to control occupational risks and identify process deficiencies.

The authors strongly recommend further efforts to address the repetition of cause trends by maximizing learning opportunities through incident learning programs that eliminate repetition trends or reduce the rate of severe injuries. Not all incidents can be prevented, but serious ones must be (Weick and Sutcliffe, 2001). This study provides critical information concerning the repetition of direct causes of incidents and highlights the importance of uncovering the root causes of fatal and nonfatal injuries. Ignoring the value of learning from incidents makes them more likely to reoccur and causes deficiencies in safety processes to go unnoticed or to become accepted as normal. The stable trend in incidents due to the same causes over time requires effective incident investigation programs at the firm level and at the national level to better learn from these incidents and prevent similar ones. The lessons learned through effective investigation programs must then be translated into effective training and outreach materials that address the root causes and deficiencies in the mechanical and electrical construction processes. This is extremely important because the industry can only prevent incidents when the root causes of incidents are identified, as suggested by Lunderg et al. (2010) and Al-Bayati and York (2019). The leading indicators discussed earlier in this section can form the core of an ideal investigation program. Leading indicators are proactive, whereas lagging indicators are reactive (Hinze et al., 2013; Al-Bayati et al, 2018). The suggested investigation programs are a strategic approach (i.e., a proactive approach) to address the reoccurrence of incidents' direct causes. Accordingly, the question is, what are the components of a proactive investigation program? The proposed investigation programs should focus on workplace factors that contribute to the reoccurrence of direct causes, specifically the workplace factors that lead to occupational incidents (i.e., incident sources and events or exposures, see Table 2). According to Jooma et al. (2015), workplace factors include incompetent leadership, inadequate supervision, inadequate training, and inadequate maintenance. Workplace factors are considered root causes because they lead to direct causes (Mitropoulos et al., 2005). The identification of root causes is vital to control and reduce the reoccurrence of direct causes.

A systematic approach is needed to identify root causes and provide practical recommendations for addressing them (Underwood and Waterson, 2014). There are several methods for identifying root causes (Mitropoulos et al., 2005). Regardless of the method, the focus should be on revealing the workplace factors that contribute to the continuous occurrence of occupational injuries. Furthermore, several versions of the chosen investigation method should be developed based on the primary sources of work-related incidents. However, suggesting an investigation program is beyond the scope of this study. The initial implementation of an effective investigation program should be viewed as a learning process that encourages continuous improvement. In addition, the proposed investigation program must be empirically validated to eliminate any possible biased (MacLean and Read 2019). Thus, investigators should be mindful of the purpose of the investigation program, which identifies workplace factors that contribute to the repetition of direct causes. Accordingly, recommendations should be made concerning the corrective actions needed to control undesirable workplace factors. Overall, the findings of this study serve to alert safety agencies of the need to develop a comprehensive investigation and learning system.

Concluding Remarks

The construction industry is composed of different disciplines and trades, among which the specialty electrical and mechanical contracting sectors play significant roles. Unfortunately, electrical and mechanical contractors encounter high rates of workplace injury and fatality. The trends of fatal and nonfatal injuries among electrical and mechanical contractors were investigated and compared to the trends reported in previous studies. The findings uncovered the most prevalent causes of fatal and nonfatal injuries and the associated tasks. This study illuminates the distinction between the direct causes of electrical and mechanical injuries and other trends in the construction industry. The results highlight the need to develop safety programs and safety management strategies that capture these differences to enhance the safety performance of specialty trade contractors. The similarities between the direct causes observed in this study and in previous studies also highlight the electrical and mechanical construction industries' failure to develop and utilize incident investigation learning programs to facilitate the development of more effective safety policies. The absence of such programs seems to significantly harm overall safety performance and create process deficiencies that enable repeat safety incidents to go unnoticed or become norms. Accordingly, this study highlights the dire need for a learning system to closely monitor the workplace factors that significantly contribute to the continued existence of the direct causes. Thus, a comprehensive incident investigation learning program is essential to provide valuable lessons that could reduce fatal and nonfatal injuries and alleviate the current shortcomings in safety practices. Therefore, revisiting the current incident investigation practices should be a priority. Finally, there are few, if any, studies that have delivered a comprehensive comparison of direct cause trends over time. The comprehensive comparison provided in this study contributes to the body of knowledge by illuminating previously unnoted trends in the causes of fatal and nonfatal injuries among electrical and mechanical contractors which, in turn, will help address these serious safety challenges.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Tasks Associated with Back, Fingers, and Hand Injuries*

Sector	Body Part	Tasks
Mechanical	Back	Material handling, poor housekeeping, slippery surfaces, and the moving of materials from one elevation to an- other
	Hand/fingers	Cutting pipe, the use of reciprocating saws, and grinders
Electrical	Back	Manually lifting heavy equipment and materials. drilling joists, installing conduits, making connections, and installing light fixtures and pulling wire through conduits.
	Hand/fingers	Installing conduits, making connections, and cutting wire (most frequent)

Source: Fredricks et al. (2002) and Abudayyeh et al. (2003)

Table 2. The BLS's OIICS System for Injuries

Aspect	Code	BLS Definition	BLS Elements
Characteristics	Nature	The principal characteristic of the disabling condition.	Sprains and strains; Amputations; Fractures; Carpal tunnel syndrome; Cuts and punctures; Tendonitis; Bruises; Multiple traumatic injuries and disorders; Heat burns; Back pain and pain; except back; Chemical burns; All other natures.
	Parts of Bodies affected	The part of the body directly affected by the previously identified nature of injury or illness.	Head; Neck; Trunk; Upper extremities; Lower extremities; Body system; Multiple body parts; All other body parts.
Circumstances	Sources	The object, substance, exposure, or bodily motion that directly produced or inflicted the disabling condition cited	Chemicals and chemical products; Health care patient; Hand tools; Machinery; Containers; Parts and materials; Floors, walkways, or ground surfaces; Vehicles; Furniture and fixtures; Worker motion or position.
	Events or Exposures	The manner in which the injury or illness was produced or inflicted	Contact with objects and equipment; Exposure to harmful substance/environment; Fall to lower level; Transportation accidents; Fall on same level; Fires and explosions; Slips/trips without fall; Assaults and violent acts; Overexertion; All other events; Repetitive motion.

Table 3. The Average of Total Number of Extracted Injuries Per Figure

Figure	Others	Electrical	Mechnical
Fig. 2. Nature of Electrical and Mechanical Injuries	79,376	11,346	11,224
Fig. 3. Parts of the body affected by electrical and mechanical injuries	70,690	10,405	10,295
Fig. 4. The source of electrical and mechanical injuries	71,267	9,757	9,885
Fig. 5. The primary event or exposure of electrical and mechanical injuries	72,896	10,238	10,253
Fig. 6. The electrical and mechanical fatal injury trends	781	79	86

Table 4. The Comparison of Trends Based on The Nature of Injuries

The Nature	Electrical		Mechanical	
	Abudayyeh et al. (2003)	This Study	Fredericks et al. (2002)	This Study
Sprains and Strains	37.0%	34.6%	41.0%	34.2%
Fractures	9.0%	10.6%	8.0%	10.1%
Cuts & Punctures	13.0%	14.0%	12.0%	13.0%
Pain	6.0%	11.1%	5.0%	10.8%
Bruises	6.0%	5.3%	6.0%	5.9%
All Other Natures	29.0%	24.4%	28.0%	26.0%

Table 5. The Comparison of Trends Based on The Source of Injuries

The Source	Electrical		Mechanical	
	Abudayyeh et al. (2003)	This Study	Fredericks et al. (2002)	This Study
Parts and materials	25.0%	23.0%	23.0%	23.9%
Floors, walkways or ground surfaces	19.0%	21.3%	15.0%	16.2%
Worker motion or position.	14.0%	17.1%	13.0%	15.8%
Hand tools	7.0%	8.9%	8.0%	9.3%
Vehicles	4.0%	7.0%	5.0%	7.3%
Machinery	4.0%	5.4%	10.0%	10.9%
Other	27.0%	17.2%	26.0%	16.4%

Table 6. The Comparison of Trends Based on The Injuries' Event or Exposure

Event or Exposure	Electrical		Mechanical	
	Abudayyeh et al. (2003)	This Study	Fredericks et al. (2002)	This Study
Contact with objects	31.0%	32.9%	33.0%	37.1%
Overexertion	22.0%	22.7%	25.0%	26.4%
Fall	20.0%	26.7%	16.0%	19.8%
Transportation accidents	3.0%	4.9%	3.0%	4.6%
Harmful substance or environment	5.0%	5.8%	5.0%	5.6%
Other	19.0%	7.0%	18.0%	6.5%

Table 7. The Electrical and Mechanical Fatal Injuries Trend

Fatal Cause	Electrical		Mechanical	
	Abudayyeh et al. (2003)	This Study	Fredericks et al. (2002)	This Study
Transportation Accidents	19.0%	14.5%	23.0%	18.2%
Assaults and violent acts	2.0%	14.6%	2.0%	20.9%
Contact with objects	7.0%	5.8%	23.0%	17.6%
Fall	21.0%	22.5%	27.0%	16.0%
Harmful substances or environments	50.0%	37.7%	24.0%	16.9%
Fires and explosions	1.0%	4.9%	1.0%	10.4%

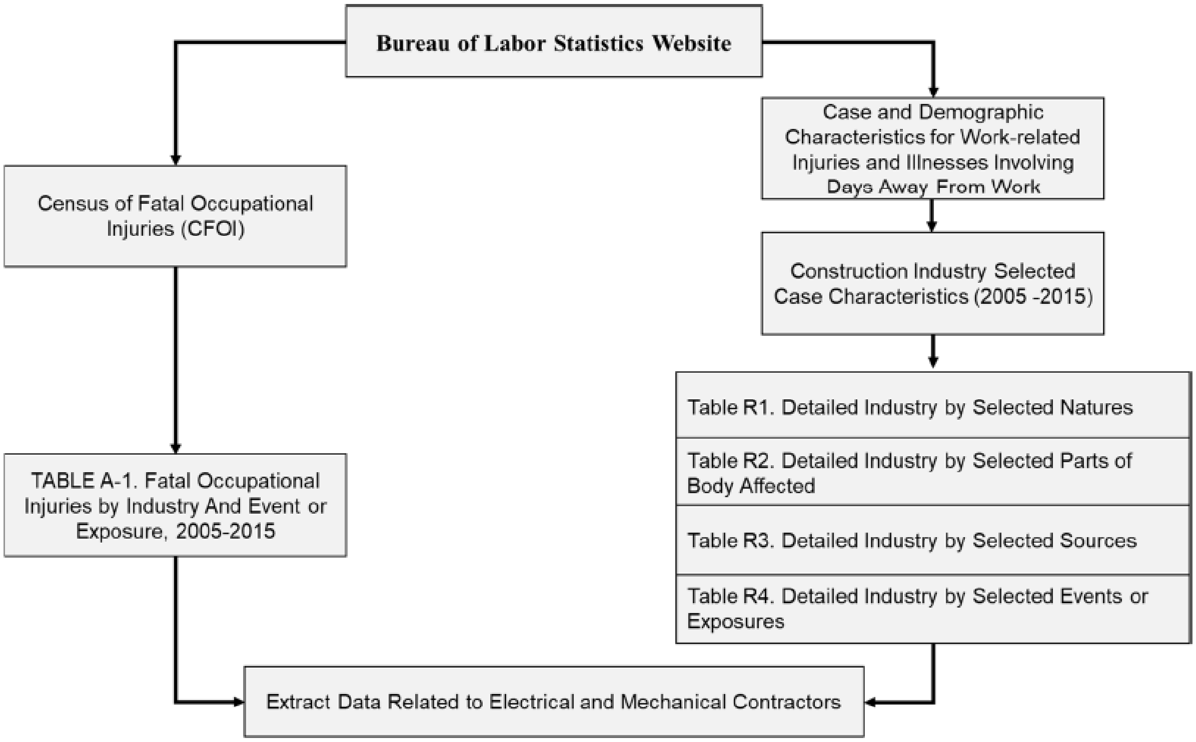
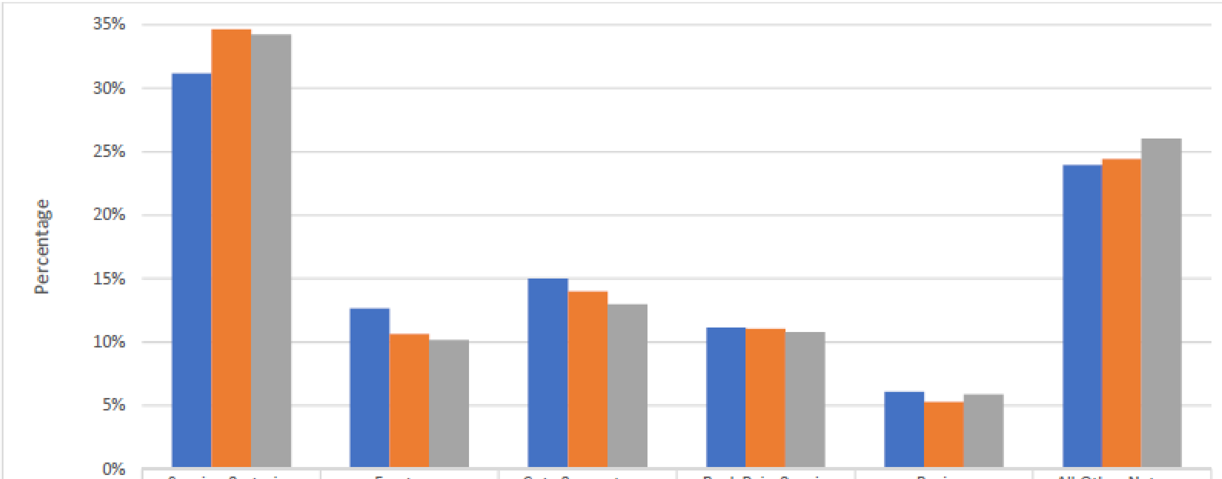


Fig. 1. The Study Research Methodology



	Sprains & strains	Fractures	Cuts & punctures	Back Pain & pain	Bruises	All Other Natures
Others	31.2%	12.7%	15.0%	11.2%	6.1%	23.9%
Electrical	34.6%	10.6%	14.0%	11.1%	5.3%	24.4%
Mechnical	34.2%	10.1%	13.0%	10.8%	5.9%	26.0%

Fig. 2. Nature of Electrical and Mechanical Injuries (2005-2015)

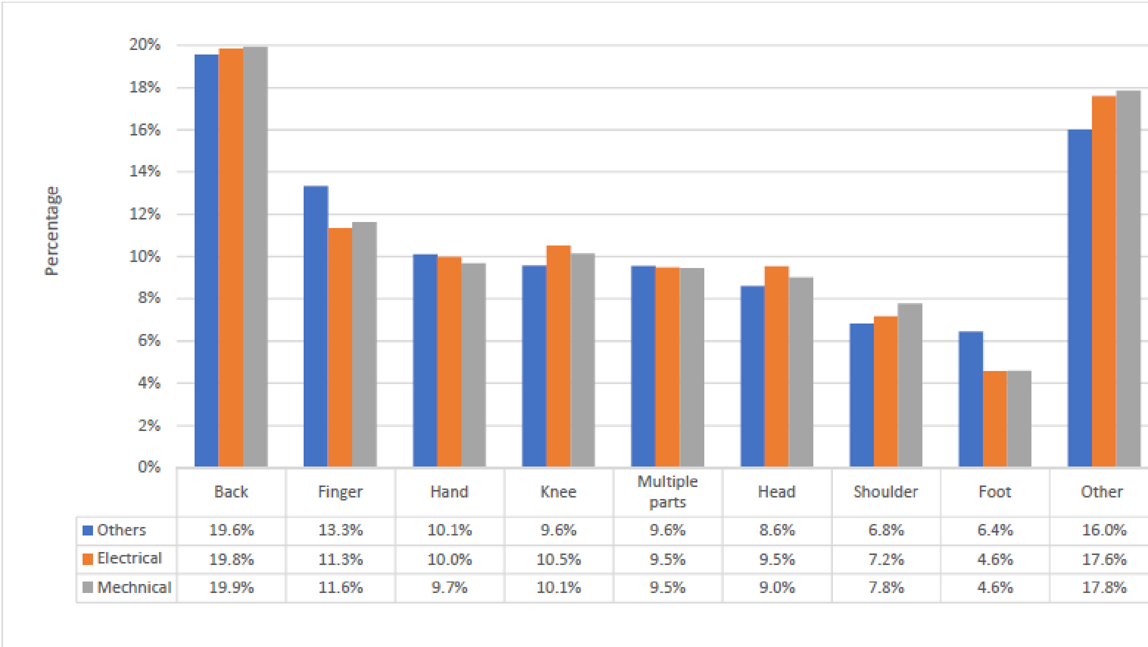
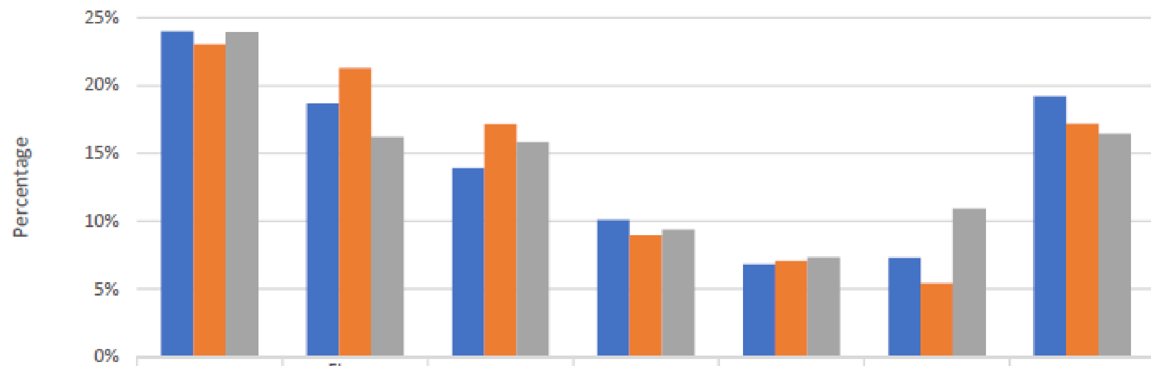
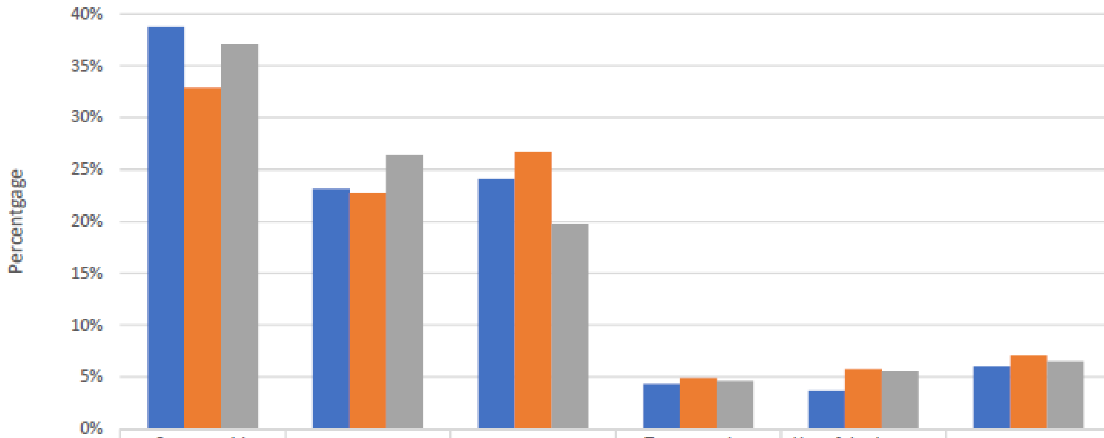


Fig. 3. Parts of the body affected by electrical and mechanical injuries (2005 – 2015)



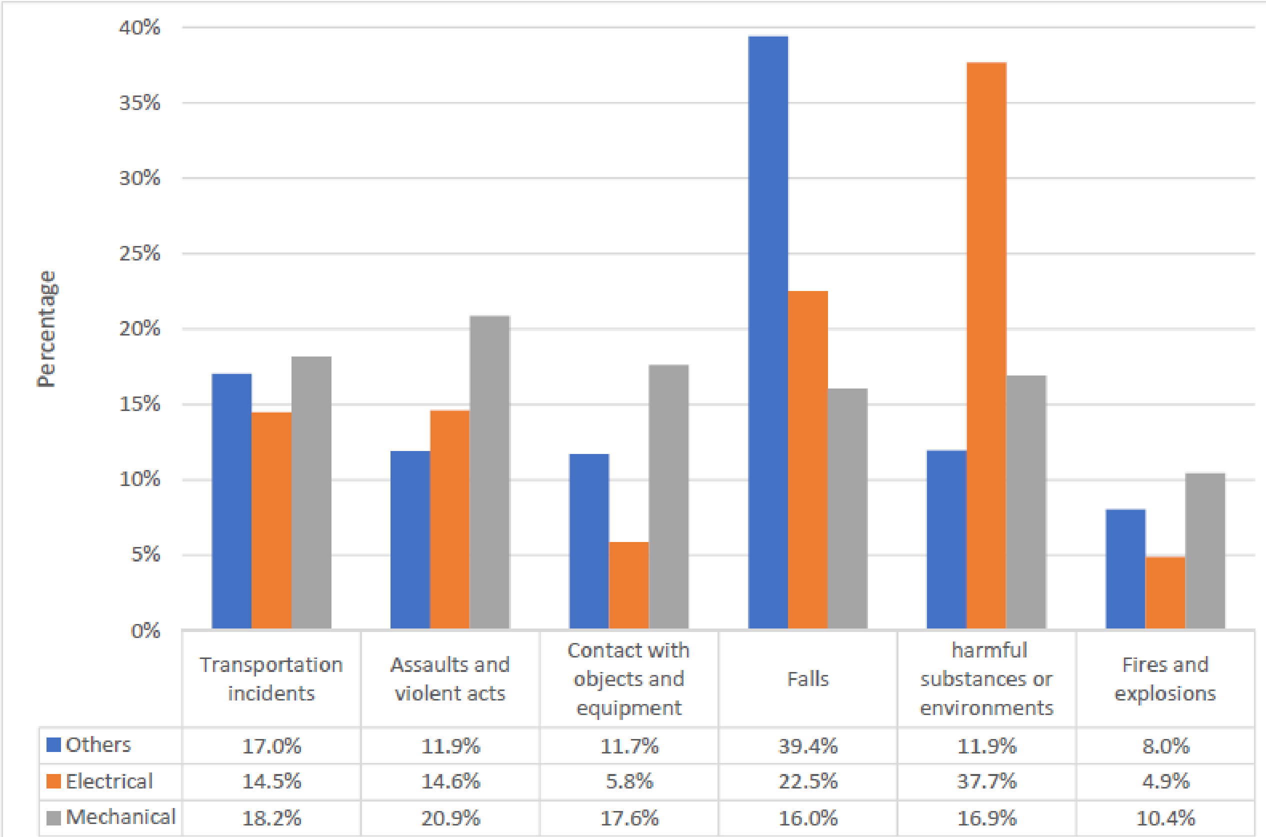
	Parts and materials	Floors, walkways, or ground surfaces	Worker motion or position	Handtools	Vehicles	Machinery	Other
Others	24.0%	18.7%	13.9%	10.1%	6.8%	7.3%	19.2%
Electrical	23.0%	21.3%	17.1%	8.9%	7.0%	5.4%	17.2%
Mechanical	23.9%	16.2%	15.8%	9.3%	7.3%	10.9%	16.4%

Fig. 4. The source of electrical and mechanical injuries (2005 – 2015)



	Contact with objects	Overexertion	Fall	Transporation accidents	Harmful substance or environment	Other
Others	38.7%	23.1%	24.1%	4.3%	3.7%	6.0%
Electrical	32.9%	22.7%	26.7%	4.9%	5.8%	7.0%
Mechnical	37.1%	26.4%	19.8%	4.6%	5.6%	6.5%

Fig. 5. The primary event or exposure of electrical and mechanical injuries (2005-2015)



	Transportation incidents	Assaults and violent acts	Contact with objects and equipment	Falls	harmful substances or environments	Fires and explosions
Others	17.0%	11.9%	11.7%	39.4%	11.9%	8.0%
Electrical	14.5%	14.6%	5.8%	22.5%	37.7%	4.9%
Mechanical	18.2%	20.9%	17.6%	16.0%	16.9%	10.4%

Fig. 6. The electrical and mechanical fatal injuries trends

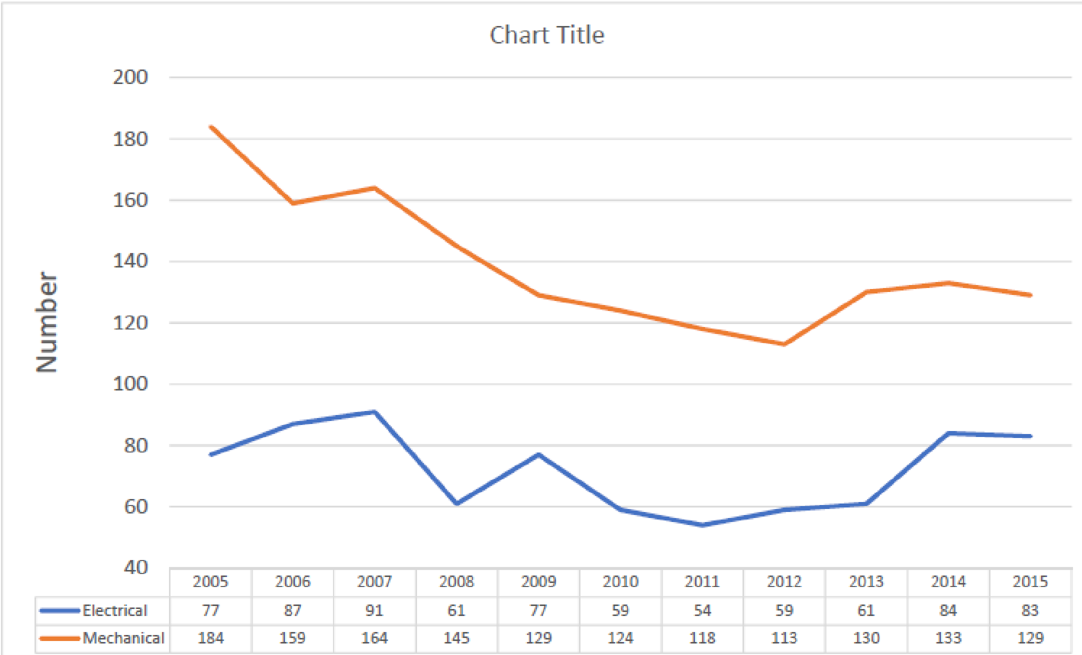
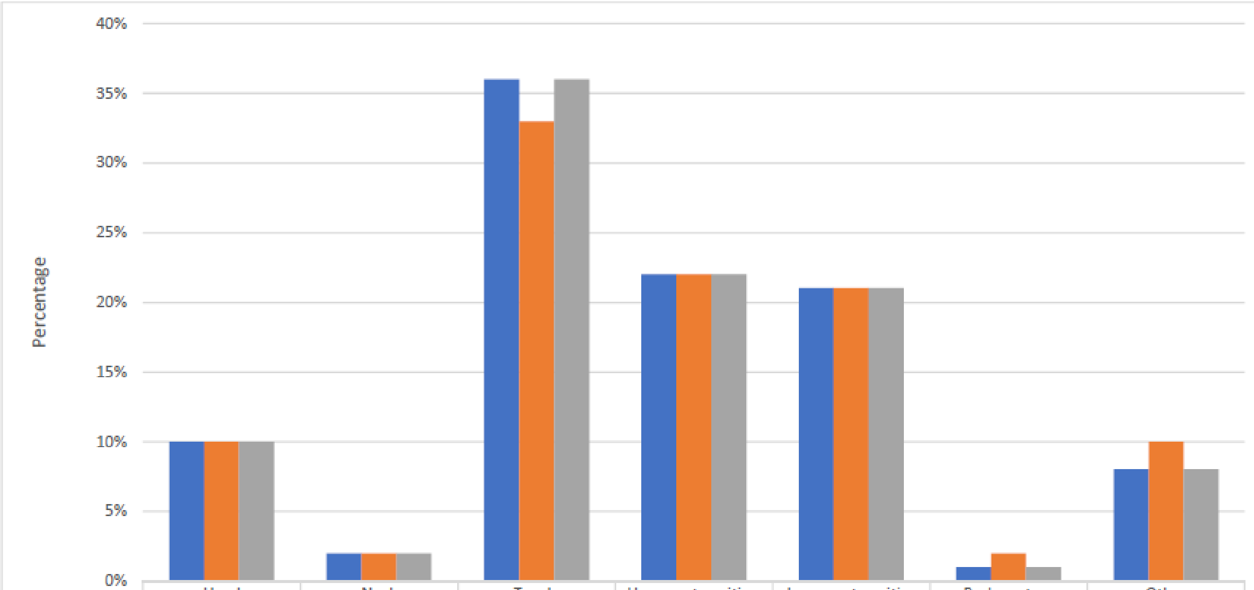


Fig. 7. The trends of fatal injuries



	Head	Neck	Trunk	Upper extremities	Lower extremities	Body system	Other
All	10%	2%	36%	22%	21%	1%	8%
Electrical	10%	2%	33%	22%	21%	2%	10%
Mechanical	10%	2%	36%	22%	21%	1%	8%

Fig. 8. The previously reported parts of body trend