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Analysis and modeling of roofer and steel worker fall accidents

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CHAPTER 1

INTRODUCTION

In the United States, there are 9.1 million construction workers in the construction industry according to the National Institute for Occupational Safety and Health (NIOSH). (http://www.cdc.gov/niosh/construction/). Construction work employs about six percent of all U.S. workers. People who work on construction sites often find themselves facing dangerous and sometimes life threatening conditions. Having multiple trades on a construction site at the same time increases the risk of an accident which can lead to injury or fatality. This research helps to identify the leading factors of the fall accidents and shows the relationship between these factors by using statistical analysis while developing models for predicting fatalities for roofers and steel workers. Safety improvements to prevent fall accidents are the ultimate goal.

Concern over the frequency and extent of industrial accidents and the associated health hazards in the U.S. led to the passage of the Occupational Safety and Health Act of 1970, which established specific safety and health requirements for virtually all industries, including construction. This act is administrated by The Occupational Safety and Health Administration (OSHA) which was created in 1971. OSHA is a federal agency that aims to ensure employee safety and health in the United States by working with employers and employees. (www.osha.gov) The OSH Act created two other agencies besides OSHA; the National Institute for Occupational (NIOSH) and the Occupational Safety and Health Review Commission (OSHRC). These agencies have different missions. NIOSH's mission is to gather data documenting incidences of occupational exposure, injury, illness and death in the United States (http://www.cdc.gov/niosh) and OSHRC's mission is to ensure that OSHA's enforcement actions are carried out in accordance with the law, and that all parties are treated in a consistent manner with due process when disputes arise with OSHA (http:// www.oshrc.gov). The responsibility for collecting statistics on occupational injuries and illnesses was delegated to the Bureau of Labor Statistics (BLS) in 1972. (http: // www. bls.gov)

Construction work includes many hazardous tasks in challenging conditions. In fact, the construction industry has the largest number of fatalities reported for any of the industry sectors in the United States. (http :// www. bls.gov)

In the US, there were 251,000 injury cases in the private construction industry and 816 fatalities in 2009. These numbers represent the seriousness of safety and health issue in construction. (See Figure 1)

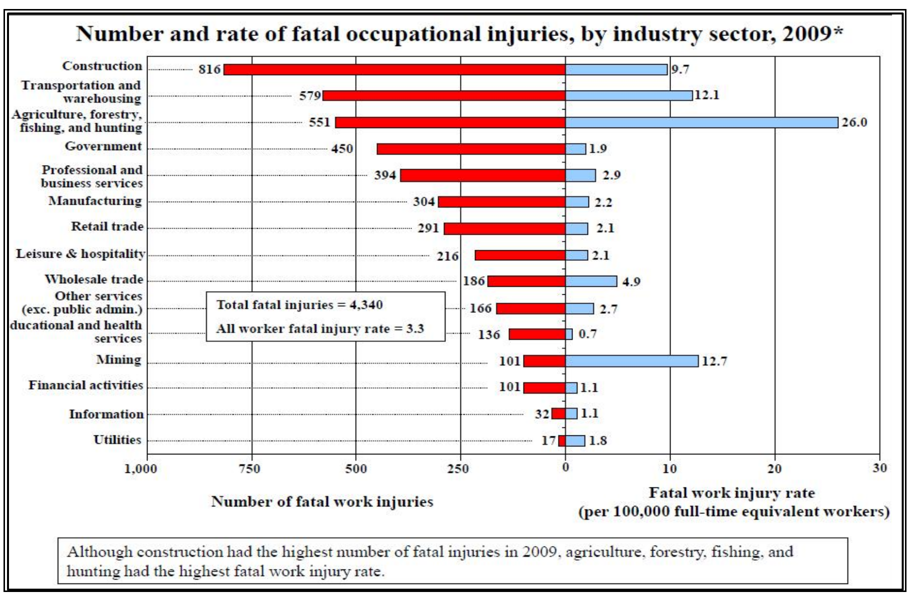


Figure 1: BLS Fatality statistics-2009

According to preliminary BLS figures, the number of fatal work injuries in the private industry construction sector declined by 10 percent in 2010. Economic conditions may explain much of this decline with total hours worked having declined 6 percent in construction in 2010. Even with the lower fatal injury total, construction accounted for more fatal work injuries than any other industry in 2010.

The BLS statistics presented in Figure 2 also show that roofers and structural steel workers are in the highest risk occupations. As observed in this figure roofers were exposed to fall accidents with a fatal injury rate of 34.7 (per 100,000full time equivalent workers), followed by structural iron and steel workers with a rate of 30.3.

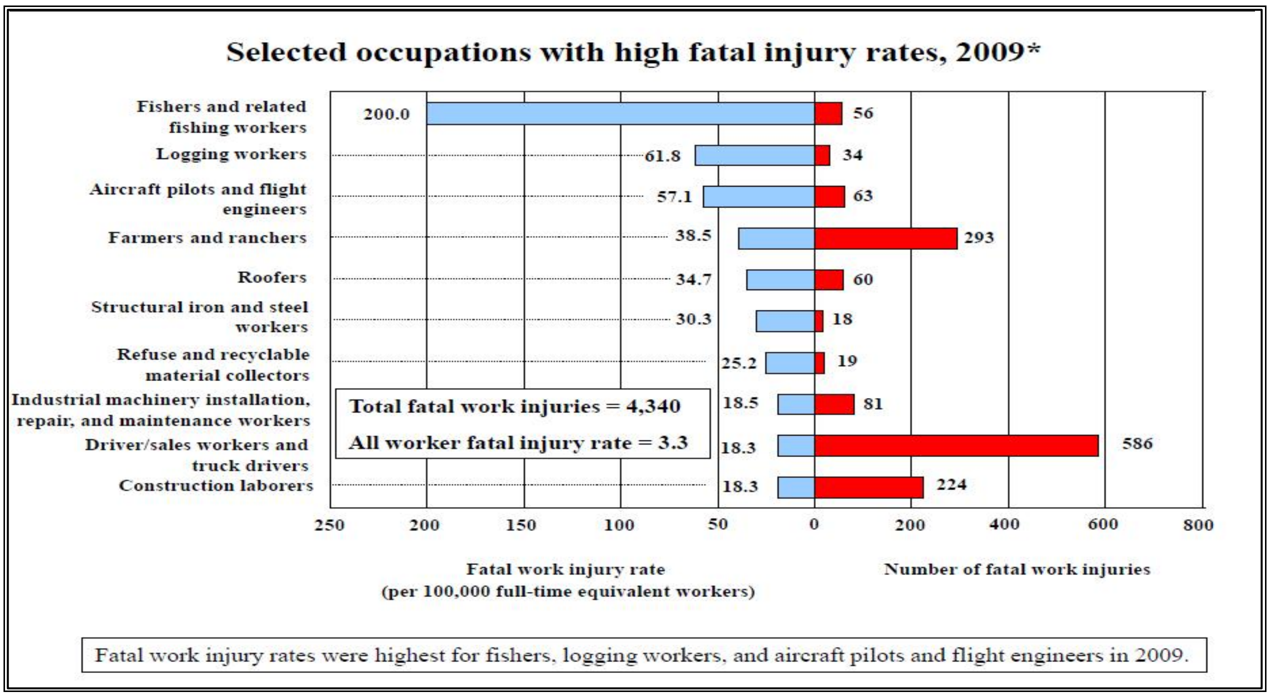


Figure 2: BLS Fatality rates by trades – 2009

The information published by Bureau of Labor Statistics (BLS) also indicates that construction industry has a high nonfatal occupational injury and illness incidence rate; which was 4.3 per 100,000 FTE workers per year in 2009, with the previously mentioned 251,000 cases as shown in Figure 3.

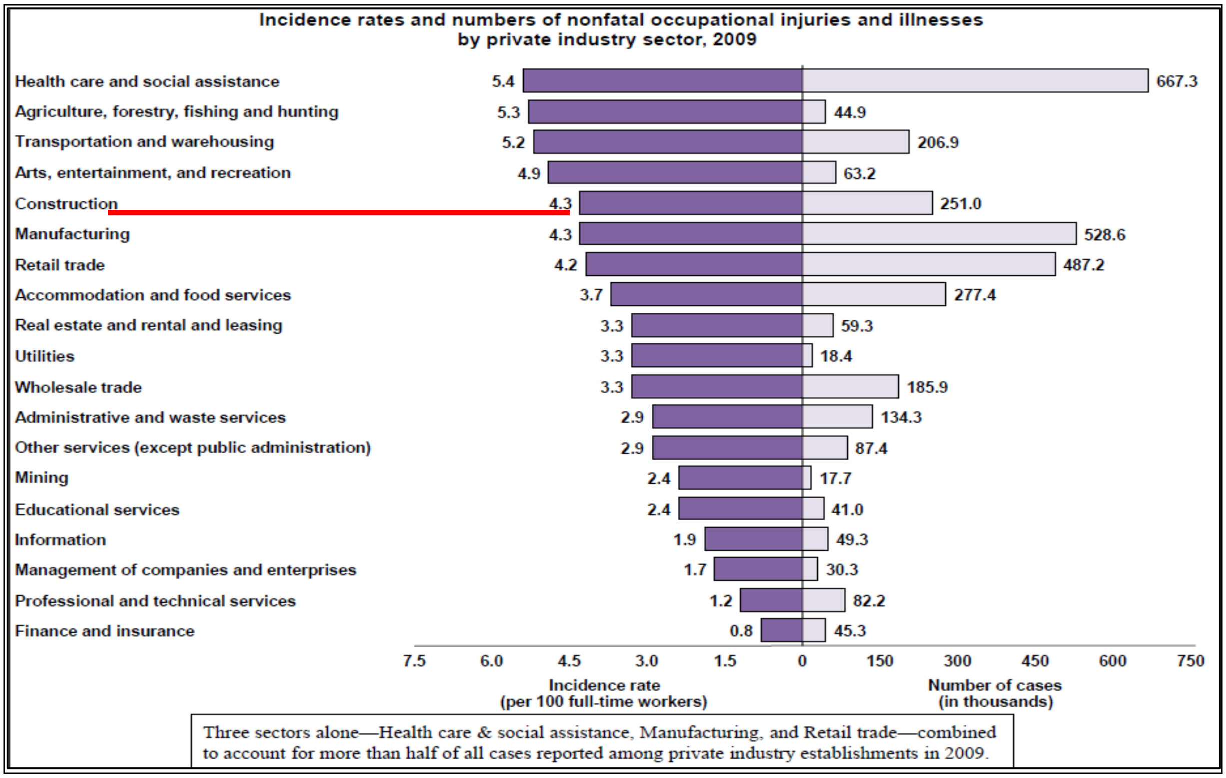


Figure 3: BLS Injury and Illness statistics by industry - 2009

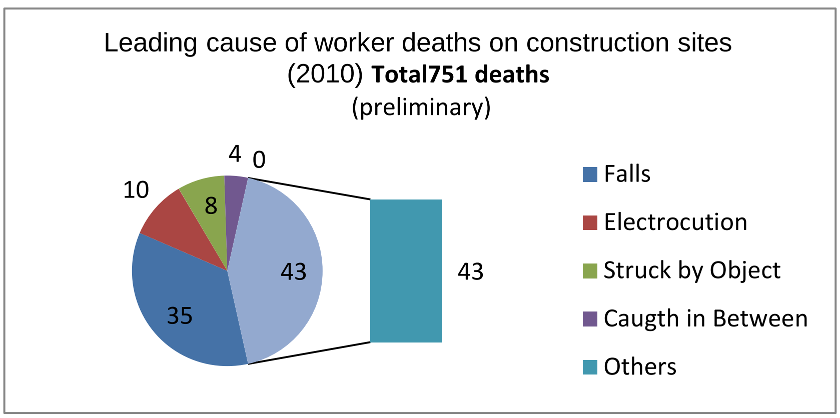
OSHA regulations dictate that all employers have a duty to protect the safety of their employees on a construction work site. On a multi-employer work site, general contractors also have a duty to implement and coordinate adequate safety precautions with their subcontractors.

Fall accidents are one of the leading causes of workplace injuries in America. Given the complexity of today's construction projects, it may be somewhat surprising that disabling or fatal accidents do not occur more frequently. Victims of these accidents often suffer injuries that prevent them from returning to work. Falls from height is a leading cause of death and injuries in the construction industry. If proper precautions are taken, and the root causes of these accidents are understood, then fall accidents can be prevented.

Falls are the leading cause of death among construction workers. They account for one-third of all construction injuries and fatalities and cause more than 68,000 serious injuries each year, according to earlier study by Rekus, 1999.

An annual report for construction site accidents is published by OSHA every year. According to this published report, “falls” are the highest occurring accidents with 277 cases in 2009. (OSHA 2010)

Causes of construction accidents are classified by OSHA as struck by, electrocution, caught in or between, falls and others. As it is shown in the pie chart below Figure 4, falls are the highest occurring injury cases among the others.



*Others: Cardiovascular/ respiratory system failure, Struck against, inhalation, Rubbed/abraded, Absorption, Bite/sting/scratch, Repeated motion /Pressure, ingestion, others

Figure 4 : Causes of construction accidents investigated by OSHA 2010 (preliminary)

As it is seen from the pie chart above; falls are the highest occurring cause (35%) among the leading causes of construction worker fatalities. This clearly explains the need of research on why this happening in spite of all OSHA regulations.

Fall from elevation is the leading cause of fatality and injury in construction and roofers and steel workers are the two most critical trades. Fall accidents are divided into

11 categories according to a classification manual that was published in 2003 by The US Department of Labor. These categories are as follows:

- Falls from stairs or steps
- Falls through existing floor openings
- Falls from ladders
- Falls through roof surfaces (including existing roof openings and skylights)
- Falls from roof edges
- Falls from scaffolds or staging
- Falls from building girders or other structural steel
- Falls while jumping to a lower level
- Falls through existing roof openings
- Falls from floors, docks, or ground level
- Other non-classified falls to lower levels

Personnel who work on heights during the construction phase are exposed to fall accidents and injuries. Unless preventive measures are effectively applied there can be serious safety problems. If fall protection safety practices are not observed at the work site, workers risk being exposed to fall hazards.

The primary objectives of this study are the following:

- To identify the factors that are potentially affecting the severity of construction fall accidents (Severity is defined as whether a construction fall results in a fatality)

- To establish the frequency distribution of the identified factors that are likely to contribute to construction fall accidents.

- To determine the relationships between the factors contributing to construction fall accidents.

- To distinguish between falls involving roofers and steel workers
- To develop models that can assist with predicting severity of falls from the contributing factors
- To establish the feasibility of using multivariate statistical analysis to model construction fall accidents using categorical variables.

Our research approach incorporated three phases. The first phase was the literature survey, which involved reviewing the information and knowledge on fall accidents in the construction industry. The second phase was data acquisition and organization. In this phase, OSHA accident records were used covering roofers (SIC 1761) and steel workers (SIC 1791) on construction sites. The data was coded and organized to construct categorical variables to be incorporated in statistical analysis. The third and last phase was to perform univariate frequency analysis, cross tabulation and logistic regression modeling. Following the literature review, the methodologies employed and the results obtained are presented in the remainder of this dissertation.

CHAPTER 2

STATE-OF-THE-ART LITERATURE REVIEW (SOA)

Construction is one of the most dangerous occupations in the American economy due to its variable, complex tasks and activities. Having more than one activity and multiple trades on a construction site at the same time increases the risk of an accident which can lead to injury or fatality. There have been many efforts by government agencies, labor organizations, and researchers in the field of health and safety for improvement and prevention; but, injuries and fatalities continue to affect the construction industry.

A review of the existing literature shows that various investigators have conducted analyses and published a number of research reports which examine frequency distribution of accidents, fatalities and injuries for a wide range of construction tasks and trades. Some studies have focused on multivariate analysis establishing the relationship between variables. They all come to conclusions on how to prevent fall accidents and/or lower their occurrence.

Scientific research has been done on workers' health and safety since 1930's. W. Heinrich (1931 &1941) pioneered these research efforts. According to Heinrich, an "accident" is one factor in a sequence that may lead to an injury. (Cleveland State University Work Zone Safety and Efficiency Transportation Center, 2003). There are many other theories of accident causation such as human factors theory, accident/incident theory, epidemiological theory, systems theory, the energy release theory. These accident theories guide safety investigations and have been used in many research projects that analyze worker accidents.

Roofers and steel workers (SIC codes 1761 and 1791) are the highest risk occupations among the construction trades. As stated in “fall protection in construction” e-book (2011) by OSHA, falls are the leading cause of worker fatalities. Each year 100 to 150 workers are killed and more than 100,000 are injured as a result of falls at the construction sites even though OSHA has rules for fall protection. OSHA rules are established at ramps, runways, and other walkways, excavations, hoist areas, holes, formwork, and reinforcing steel, leading edge work, unprotected sides and edges, overhand brick laying, and related work, roofing work, precast concrete erection, wall openings, residential construction, and other walking/working surfaces. According to the OSHA rules, employers have the responsibility to protect the employees from fall hazards and falling objects whenever a subjected employee is 6 feet or more above a lower level.

2.1. CONSTRUCTION ACCIDENTS

Occupational injuries and fatalities among construction workers have been a great concern to the construction industry. Researchers have analyzed existing reports to categorize the most common types of accidents. Not only the type of accidents but the specific trade types and how accidents happen have also been studied by researchers. (T.J. Parsons et al., 1986)

Abdelhamid and Everett (2000) identified three root causes in their published study of construction accidents. These causes were: (1) failing to identify unsafe conditions that existed before the start of the activity, (2) deciding to proceed even realizing the unsafe condition; and (3) deciding to act unsafe regardless of the conditions. They also identified four unsafe conditions and their reasons, which were:

(1) management actions/inactions; (2) unsafe acts of worker or coworker; (3) non-human-related event(s); and (4) an unsafe condition that is a natural part of the initial construction site conditions. By creating an accident root causes tracing model (which is a cause and effect diagram) they presented the accident investigators a tool to determining the root causes of the accidents. The model provides a tool for determining the areas that require more inquiry as a means to find facts about the causes of particular accidents.

A study was conducted by the Construction Industry Research and Policy Center at the University of Tennessee, Knoxville for OSHA's Office of Statistics (2011). In order to inspect fatal events in construction during the 2003 this group implemented univariate frequency analysis on 707 accidents that occurred that year using OSHA accident reports. Fall from/through roof led all other causes in number of fatal events (76 or 10.7 % of total fatal events), followed by fall from/with structure (74 or 10.5 %). The third leading cause was crushing/run-over of non-operators by operating construction equipment (7.9 %); followed by electrocution by equipment contacting wire (6.6 %); electric shock from equipment installation/tool use (6.1 %); and trench collapse (5.8 %).

They also prepared a comparison of the year-to-year ranks of the proximal causes during the years of 1991-2003 and calculated by using a Spearman rank correlation procedure. This statistical test showed that individual ranks of the causes vary very little from year-to-year. The author also analyzed and classified the fatal events by victim's situation (Figure 5) and fatal events by work status of the victim. (Figure 6)

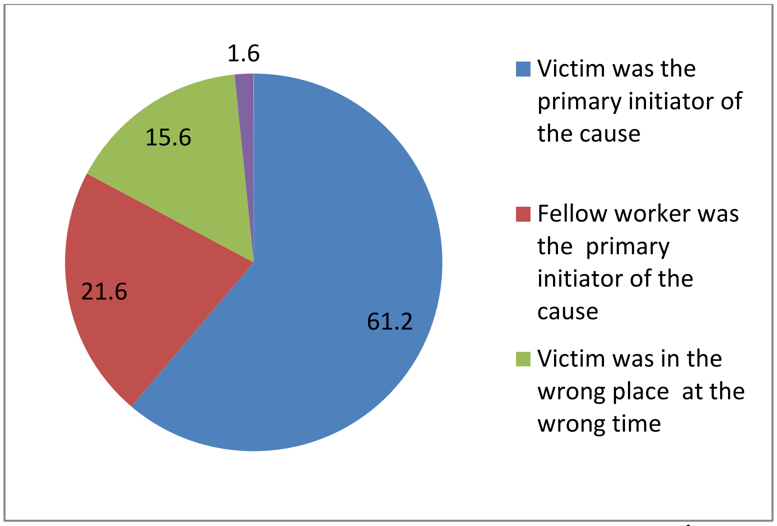


Figure 5: Fatal events by victim's situation[1]

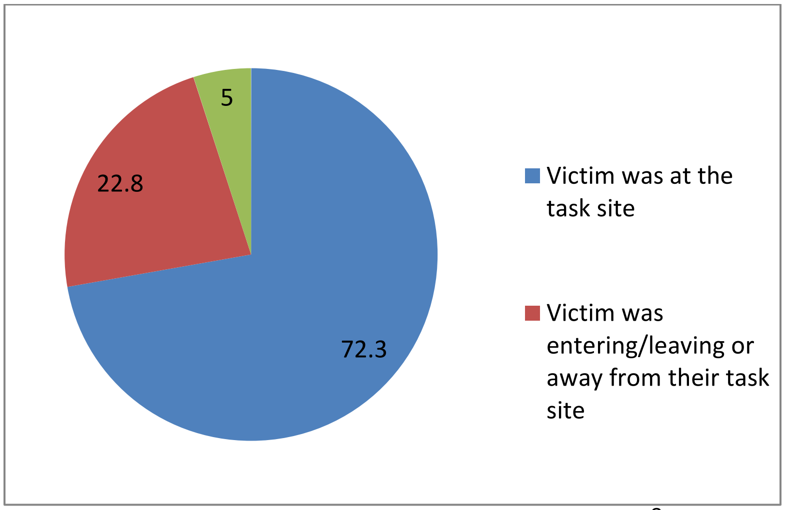


Figure 6: Fatal events by work status[2]

As can be seen from the pie charts above, task (main work) site was the most frequently occurring place for fatal accident and the victim, himself, was the primary initiator of the fatal accident. This study may shed some light to the effects of human factors and environmental factors on fatalities.

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[1], [2] Author of this dissertation using data from the original records.

Sawacha, et. al. (1999) prepared questionnaires after conducting exploratory interviews of several safety related personnel in the construction industry. The questions were related to research variables, covering historical, economical, psychological, technical, procedural, organizational and environmental factors. Safety performance was considered to be dependent variable. Among the variables that were found to be significant were the operatives' age, job experience, danger money, productivity bonus payment, safety bonus payment, personal care for safety, impact of Health and Safety act, ongoing safety training on site, supervisor's safety behavior, asbestos awareness, use of ladders, scaffolding fixing and inspection, steel erection, training on use of safety equipment, issuing of safety booklet, worker-management relationship, control on sub-contract's safety behavior, site safety representative, management-worker co-operation on safety, Safety committee policy, talk by management on safety, safety poster display, planned and organized site (layout) and tidy site.

The authors used Pearson's correlation coefficient (for linear) and factor analysis (for non – linear groupings) to measure the strength of the relationship between the research variables and safety performance. According to their findings there was a strong relationship between the worker age and experience and their level of safety performance. The worker age group between 16-20 was more prone to accidents and after age of 28 accidents were tend to decline. They claimed that experience had a lowering effect on accidents meaning experienced workers were more aware on safety requirements. The high correlation between safety performance and hazard payment and productivity bonus payments suggest that the workers who were paid hazard money or productivity bonus subject to higher risk of accidents because they tended to act unsafe in order to achieve higher production. They also found a strong correlation between safety performance and psychological variables. The authors indicate that workers who showed concern for personal safety had a better safety record compared to those who did not. The author's statistical work did not show any relation between workmates safety behavior and safety performance. For the technical factors and safety performance there was a significant relationship found between hazard awareness and safety performance but not handling. When the procedural factors were investigated, it was seen that providing safety kits alone did not have a diminishing effect on accident occurrence but providing safety training on how to use these kits had a lessening effect on accident occurrence. Organizational factors were found to be all linked to safety performance. Managements' viability and involvement had positive effect on successful safety performance. They found a strong relationship between environmental factors and safety performances which might translate to good housekeeping practices and well planned out sites provide higher safety performance.

Marion Gillen, et. al. (2002), in their study titled, "injured construction workers' perceptions of workplace safety climate, psychological job demands, decision latitude, and coworker support, and the relationship of these variables", used several questionnaires involving these variables. Based on the survey, the authors found significant positive correlation between injury severity and the safety climate scores, and between the safety climate scores and union status. They stated that there were statistically significant differences between union and nonunion workers' responses regarding perceived safety climate. Union workers were more satisfied with safety climate than non-union workers due to their safety awareness. The authors recommended that dangerous work conditions and practices should be explained to workers more often. The workers who practice safety should be praised for setting examples on construction sites. This is one of the few studies that use multivariate analysis on the construction safety and findings can be used to evaluate the safety training methods and practices.

Many architects who have worked in the construction industry believe that the design process should consider construction safety. Fall protection should ideally begin at the designing stage and it should be the duty of the designers to work on the design with the aim of providing safety for the workers in the work site. If the designers incorporate certain requirements in to the design to initiate the safety from the beginning of the project that would greatly benefit the workers' safety (J. A. Gambatese, et. al. (2005), M. Weinstein, et. al. (2005), M. Behm (2005)).

Gambatese and Hinze (1999) addressed this issue in their research entitled "Designers can positively influence construction site safety by integrating safety considerations into the design process". They stated that designer involvement in construction safety in the U.S. is a voluntary effort. Only in design – build firms, designer and construction professionals work together and understand the importance of incorporating construction safety in design. This research work aimed at developing design suggestions. The authors recorded all the suggestions applicable to safety design for construction projects. They used safety manuals, checklists, interviews and various literatures to develop the mentioned suggestions. They observed from OSHA accident reports of 1985 through 1989 that the majority of fatalities are from falls from elevations and comparably the recorded suggestions were the highest in that area. Some of the suggestions were: designing parapets 42 inch instead of 30 inch to satisfy the OSHA guardrail requirements; and designing and scheduling permanent staircases at the beginning of the construction to eliminate temporary stairs and scaffolding hazards.

P.G. Furst (2009) is another author who has addressed the importance of incorporating safety measures in design. The author pointed out in Figure 7 how safety can be influenced and incorporated in projects in different phases of a construction process. Furst showed that the opportunity to prevent construction accidents was the highest during the planning phase, and adopting preventive measures would be harder to apply to the projects once they reached the construction phase. He suggested that there were new technological advancements in computer science technology, such as Building Information Modeling (BIM), which could be adopted so construction hazards could have been seen beforehand and preventive measures could have been taken before accidents occur.

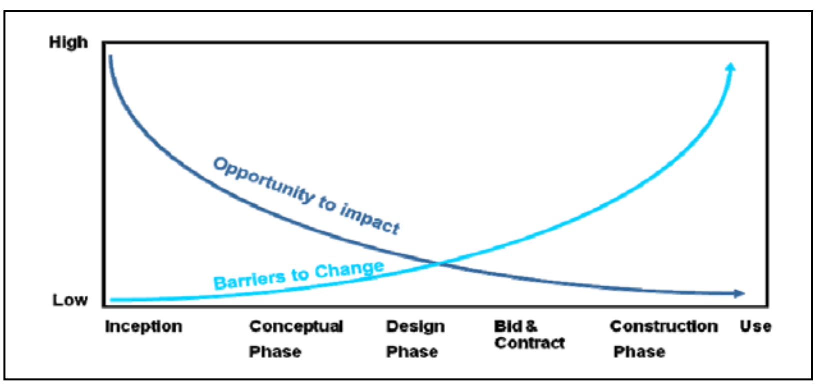

Figure 7: Impact and change graph during construction phases. Furst, Peter G., 2009, “Prevention through Design (Safety in Design)”

Similarly, many other authors (J. A. Gambatese, et. al. (2005), M. Weinstein, et. al. (2005), M. Behm (2005) conducted research on safety design which suggests the incorporation of the needed safety preparation times to be added to project scheduling. The only obstacle to incorporate the safety design concept to the design phase of a project is educating the designers and the owners of the projects in terms of safety design requirements and the extra time and expense required.

From a different perspective, Gillen et al (2004) carried out a qualitative investigation by interviewing 22 construction managers. As a result of this interview they came to the conclusion that “developing and expanding management skills of construction managers may assist them in dealing with the complexity of the construction work environment, as well as providing them with the tools necessary to decrease work-related injuries.” This is useful research on the acknowledgement of construction manager’s role on construction safety.

G. A. Howell, et. al. (2002) stated in a paper in the proceedings at the 10th Annual Conference of the International Group of Lean Construction that, over the years, construction safety had significantly improved but more improvement might come from either applying best practices in the construction industry or from “breakthroughs” that exceed the best practices. They claimed that “adopting a new definition of hazard and applying better planning can enlarge the safety zone” and create fail-free tasks. Their recommendation of worker training, worker motivation, pre-task hazard analysis and post-accident analysis can serve as keys to preventing accidents.

X. Huang’s (2003) doctoral dissertation focused on the owner’s role in construction safety. In this study, the author surveyed the relationship between project safety performance and the owner's influence. The author sent survey questionnaires to the owners of the big construction firms with at least 100,000 worker hours per year, and used the survey results for statistical analysis. The author chose the OSHA recordable injury rate as the dependent variable and different safety management techniques as the independent variables in the analysis. In the first phase of the analysis, descriptive statistics were used to obtain the frequency of several safety practices. In the second phase, the association between the variables were tested, and in the third phase a model to explain the cause and effect relationship between project safety performance and several ways to owners' involvement to safety in construction safety management was developed. The author also created a scorecard to evaluate owner involvement in safety. Based on linear regression modeling there was a strong cause and effect relationship between the owner's involvement, together with the project characteristics and the contractual safety requirements, and the project safety performance. The author also created a project scorecard to evaluate the safety performance of a project. The owners could use the scorecard to evaluate the safety performance of the project. Also there are a number of studies (R. S. Harper and E. Koehn (1998), O. Abudayyeh, et al, (2006)) done on managements' involvement in construction safety. These studies clearly show the importance of manager/owner involvement.

Baradan and Usmen (2005) used Bureau of Labor Statistics (BLS) data to study and rank the risk factors and levels of building trades. The authors defined risk as the product of the probability and severity and adopted the "risk plane concept" to evaluate and rank the trades in terms of non-fatal injury rates. For the fatality rate based ranking they used the" index of relative risk", and combining two separate analyses, they defined a combined risk score. Authors state that risk analysis based on both severity and probability taken together is more comprehensive than performing separate analysis. The authors also stated the fact that the highest number of fatalities among all industries happens in construction. The information developed from the methodology in this paper is very valuable for risk managers and project managers among many others.

In their risk-analysis the authors developed a two-step approach. First they have analyzed the fatal and non-fatal injuries separately. Second they have combined risk analysis of the two into an integrated risk analysis. Their results showed that the iron workers have the highest non-fatal injury rate followed by roofers. The construction workers have the highest median days away from work and cost of lost time among all trades. Roofers and ironworkers are the top two trades in fatality rates. As a summary, roofers and ironworkers ranked the highest in both non-fatal and fatal injuries and posed the highest overall risks.

2.2. FALL SAFETY

Many studies have been conducted on falls and their prevention since the 1980's. These studies have covered topics ranging from causes of the falls, falls from the roofs, falls from the scaffolds and studies of the falls by type and scale of the projects. The literature includes several occupational safety articles specific to falls in construction.

A research study by X. Huang and J. Hinze, (2003) focused on the data OSHA accumulated on construction worker accidents involving falls between January 1990 and October 2001. The authors' aim in this study was to identify the root causes of fall accidents and any information that might be helpful in reducing construction falls in the future. Although the authors used a simple approach to analyze their data, the findings of this research were quite comprehensive. However, there was a missed assumption where the authors assumed all victims had experience in construction. From the data they provided in their paper, this could not be proved. Despite this point, the authors' conclusion on fall height occurrence would help the construction industry to focus more on fall protection in certain heights during small commercial and residential construction.

The study was conducted to determine the causes of construction fall accidents identify any particular patterns related to them and determine the impact of OSHA regulation changes on fall prevention. Data used in this study was gathered from OSHA investigations between the years 1990 through 2001. A total of 7543 cases were identified; however, only 2955 cases were used in the study.

The paper analyzed the data according to different descriptors such as; the time of fall occurrence, projects involving falls, fall height, and injuries resulting from fall accidents. The authors also determined the immediate causes of fall accidents, which were: work operations resulting in falls, the location of falls, and human errors resulting in falls.

The authors concluded that falls were the most common accidents in the construction industry, and they were the main cause of fatalities and serious injuries. The authors warned safety personnel to pay extra attention to safety precautions for heights over 30 feet. The authors also found that carpenters, roofers, and structural metal workers should receive close attention and be trained accordingly.

The authors used data which was sent in Microsoft Access format which could be easily converted to files that could be manipulated by a statistical package for the analysis. The authors not only used a simple approach to analyze the data , such as bar charts, pie charts, tables, plot charts, but they also clearly showed the most frequently occurring fall accident heights in construction, while tying it to construction costs.

According to the authors, workers between the ages of 31 through 40 are the most susceptible group to fall fatalities and suggest that work experience does not contribute to cautious behavior in construction fall accidents.

The authors stated that among the 2741 fall accidents, 1018 cases indicated the height of the projects and the number of stories. They pointed out that in 801(81 %) of the projects fall accidents occurred with either one, two or three stories, and the average building height was 37.4 ft. They concluded that more than 70 percent of the fall accidents had occurred at heights less than 30 feet.

The authors proposed that the construction industry should pay more attention to with small commercial and residential constructions. They also implied that even though OSHA regulations strictly state all fall preventions should be implemented at all elevations above 6 ft., fall prevention techniques may be too relaxed at lower elevations in some projects, which is a very important point.

The authors used the OSHA database to see if there is an obvious pattern among the fall accident reports that may be used to caution the construction industry. Their statistical work identified numerous points that may enlighten the construction industry on prevention of fall accidents. It was emphasized that 30 feet and lower heights were the most susceptible to fall accidents; therefore, construction industry should pay more attention to the lower heights.

While this paper delivered useful information, the author's assumption that all the workers in this age group must have had some experience without the support of any records can be questioned. The authors do not describe the methods of how they identified this age group of workers as experienced workers. The only weak point in this research was lack of data on how they have drawn the conclusion on 31-40 years old age group are the experienced construction workers. The authors should have had the data on workers job experience in order to come to conclusion on experience had no positive effect on fall prevention. Also, it may be a good idea to repeat this research in 5 year intervals and see the effects of their recommendations on construction industry while identifying new patterns of fall accidents, if any.

When we review the literature in terms of trade types there were several studies done on roofers. According to a study by the Center for Construction Research and Training (www.cpwr.com), (2000), on the causes of roofers deaths, it was found that roofers had the fifth highest work related death rate in construction. They analyzed a total of 359 deaths for a seven year period. As seen in Figure 8, falls are overwhelmingly the main cause of the deaths among roofers.

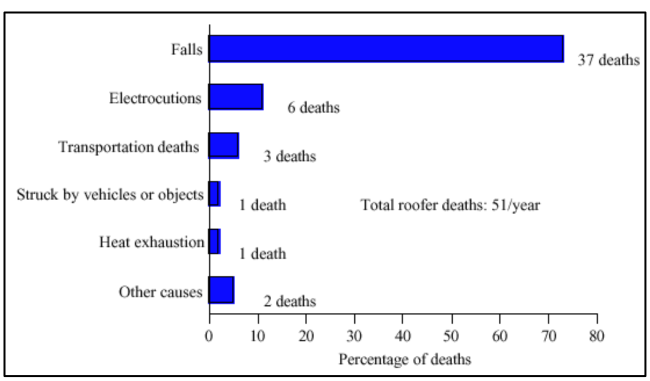

Figure 8: Causes of work-related deaths, roofers, United States, yearly average,1992-98 (www.cpwr.com)

The causal factors for roofer fall fatalities are shown below in Figure 9 indicating that falling from the roof edges were the most frequently occurring incidents followed by falls from ladders.

A total of 262 fall deaths were analyzed in a seven year period elapsed between 1992 and 1998. The document states that in residential construction, falls from roof edges accounted for 70% of work-related-fall deaths and 90% of roof fall deaths for roofers.

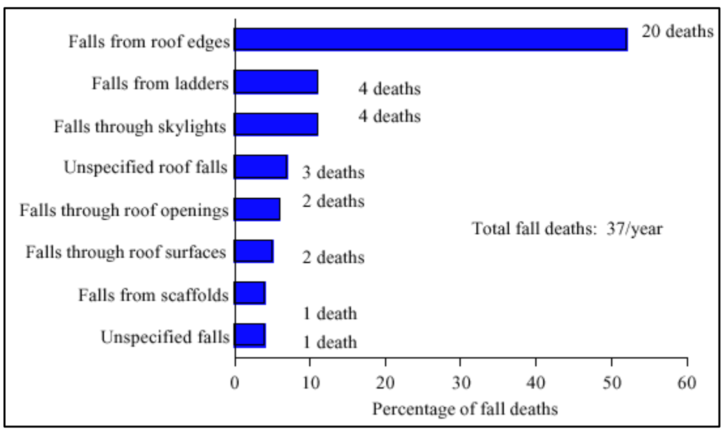

Figure 9: Causes of deaths from falls, roofers, United States, yearly average, 1992-98 (www.cpwr.com)

The study claims that the lack of adequate roof-edge fall protection was the reason even when this was the clear requirement of OSHA. It also suggests that guardrails, safety nets, or personal fall-arrest systems could have prevented most of these deaths. This paper also claims that OSHA's permission to use warning lines and safety monitors were not serving as effective preventive measures. Several recommendations were made to contractors and roofers to prevent fall accidents. These recommendations are roofer safety training, usage of traditional means such as guardrails and personal fall arrest system, solid covers on roof openings, guardrails around skylight openings; de-energize the overhead power lines before the work. This paper used a simple frequency analysis technique. The recommendations presented are general commonsense recommendations and regulatory requirements which should have been enforced on a continuing basis.

In another study, K. L. Hunting et. al. (2004) focused on occupational injuries among construction workers to identify injury patterns for further examination and developing aversion programs. They created a log entering all the injuries that were treated in the Washington Hospital between 1991 and 1997. They identified 2,916 injured workers. The analysis showed that falls were the second injury causing factor among all possibilities. When compared to other trades, steel workers were more susceptible to falls, and 21% of the 133 steel workers had experienced falls compared to 17% of the 2783 injured workers belonging to other trades.

Slips and trips were the major cause of falls. The authors' recommendation for slips and trips was more-efficient material staging practices. This study represents a good observation on causes of falls for steel workers. Some important variables such as human factors and victims' training / retraining on fall safety precautions were missing from the study to develop adequate recommendations. However, the study opens the door to further investigations. This study, as well as the previous one, show that falls are the main culprit for accidents involving roofers and steel workers.

Chia et al, (2005) reviewed 621 case reports that covered occupational fatal falls occurring during the years of 1994 through 1997 in Taiwan. Their aim was to create accident scenarios to propose prevention measures. They extracted various factors from the case reports that might have had an effect on the accident, such as: type of the industry, age, gender, experience level of the victim, source of the injury, the company size (number of the workers employed), and accident type. Their frequency analyses showed that majority of the victims were male and aged between 25 and 44; worked for companies with fewer than 30 employees; and had less than one year of work experience. They used multivariate analysis (Chi square test) to establish the relationships between factors. There were significant relationships between gender and cause of fall that showed that females were more likely to fall from heights. The authors attributed this to the lack of communication between the female and male workers. This reasoning does not seem very convincing but the social and physiological conditions of Taiwanese female workers may affect this conclusion. They also looked at the relation between the cause of fall and accident event. They determined the causes of falls as; unguarded openings, poor work practices, inappropriate protection, improper use of personal protective equipment (PPE), distraction, unauthorized access to hazardous area, unsafe ladders and scaffoldings, and removal of protection measures. The authors report the lack of accompanying scaffolding and bodily action as the main causes' of falls from scaffolds and staging and they recommend usage of guardrails. The study also revealed that inexperienced workers and workers who work for small companies are exposed to greater risks of fall accidents.

T. K. Fredericks, et. al. (2005) similarly reported from their research that roofers who work on small companies (less than 11 employees) were in higher risk of falling from the roof than big companies. Even though this study had used a significant analytical approach to study the relationships between the cause of fall and other factors, the recommendations came out to be well known, common sense approaches, such as: safe work practices associated with roofing tasks.

M. G. Helander (1991) researched 739 fatal construction accidents in England. He categorized the accidents and found out that the most frequently occurring accidents were the falls.

C. A. Janicak (1998) also studied fall related fatal accidents, and his results were in agreement with those of the previously mentioned study by Huang and Hinze (2003). The author used fatality inspection reports of OSHA for the years 1992 through 1995 and categorized the 566 cases by the cause of fall. He used three different types of statistical analysis; first was ANOVA to identify the significant differences in the mean distances of falls based upon the cause; the second was PMP (proportionate mortality ratios) for fall cause within the construction industry and the third was Mantel – Haenszel Chi square of significance test to determine if the observed deaths were significantly different from the expected. Table 1 below, created by Janicak, "The cause of fatal work-related death in the construction industry", shows that the lack of protection in place was the most frequently identified cause appearing in 35.3% of all deaths from falls.

Table 1: The cause of fatal work-related death in the construction Industry (Janicak 1998)

Cause	Frequency	Percentage
No Fall Protection	200	35.3
Structure/equipment collapse	128	22.8
Slip-fall off ladder	57	10.1
Fall protection not attached	36	6.4
Improper work surface	33	5.8
Damaged fall protection	20	3.5
Erecting/dismantling scaffold	18	3.2
Other	17	3
Unknown	57	10.1
Total	566	100

The author also reported that fall accidents occurred mostly from work heights of 12 feet or less. He identified two different types of falls, falls from ladders and falls on the same level due to slips and trips.

According to Janicak's data presented in the Table 2, roofing workers are those who are most frequently involved in fatal accidents. The author also emphasized prevention techniques. He mentioned that commonly 45% of the accidents occurred when there was a fall protection system in place, but the victim of the accident was not using it. The author called attention to this issue and suggested that companies should enforce the usage of fall protection systems when workers need to work on heights. He also indicated the importance of good housekeeping to prevent falls on the same level.

As a final suggestion Janicak recommended that companies should give adequate training to the workers on how to properly install, use, test, and inspect fall protection systems.

Table 2 : Fatal work-related falls by construction trades (Janicak, 1998)

Industry	**Frequency**	**Percentage**
Residential	26	4.8
Non-residential building	68	12
Highway and streets	9	1.6
Heavy Construction	44	7.8
Plumbing and heating	23	4.1
Painting	35	6.2
Electrical Work	40	7.1
Masonry	46	8.1
Carpentry	32	5.7
Roofing	109	19.3
Concrete	13	2.3
Miscellaneous trades	121	21.4
Total	566	100

Cattledge, et. al. (1996) analyzed the death certificates of all fatal falls in the construction industry between 1980 and 1989. They reported that 49.6% of deaths were from falls, and most of them were white young males, a finding which was also underlined by Xinyu Huang and Jimmie Hinze's (2003) research. Construction industry's domination by male workers can be the explanation of this finding.

F. C. Hadipriono (1992) focused on the engineering aspects of construction falls from elevated openings (wall & floor, floor working platforms, roofs and scaffolds) in his research. He used "Fault Tree Expert System Model" (a graphic model that shows parallel and sequential causes of events that contribute to a predetermined top undesired event) to investigate and prevent unintentional falls on a construction site. He benefited from literature reviews to establish the causes of construction accidents and their relationship, and represented them in a fault tree system. He divided the fall causes into three distinctive areas: 1. the enabling causes (internal problems suffered or experienced by the worker). 2. the triggering causes (active external events, causing the worker to fall). 3. the support-related causes of the fall (passive, external events, indicating the failure of components supporting the worker). In addition to graphical representation of the fault tree models, the author also prepared qualitative analysis on possible causes and combination of causes that resulted in falls. This study produced a beneficial tool for experts to diagnose construction falls using after the fact data.

Suruda, et. al. (1995), in their paper named "Fatal Work-Related Falls from Roofs"; provided general information on falls from roofs that can be useful in planning preventive measures. The authors' stated their purpose as examining the extent of falls from the roofs.

In their data collection the authors used the death certificates of workers who died. The National Institute for Occupational Safety and Health (NIOSH), National Traumatic Occupational Fatalities (NTOF) database was used to obtain the death certificates. This database includes all U.S deaths in 1980 and after. In these certificates the ones where “injury at work” box was checked “yes” and “external cause of death” was an “injury” according to the International Classification of the Diseases, Ninth Revision (ICD-9, 1975). The authors chose the victims whose ages were16 and older and certificates with the ICD-9 codes E800-E999 were searched for the years 1984 to 1986. Among these ICD codes E880-E886 or E-888 were the causes labeled as deaths from falls. Also, they used a computer search of the certificates for the words; “roof”, ”skylight”, “parapet”, “deck”, “rooftop”, “cover”, “dome”, “plastic”, “insulation”. These records were then reviewed manually to determine if the fatal fall was from the roof. The authors excluded the records from California, Michigan and Washington states due to format incompatibility.

Suruda, et. al. (1995), matched all the NTOF records to the OSHA fatality investigations of falls mentioning roofs. In this process they matched the records by location, date of death, worker’s age and the site of fall. Bureau of the Census’ County Business patterns (CBP) was used as the denominator for calculating rates based on the Standard Industrial Classification (SIC).

Falls from roofs were categorized according to location. First they were categorized as the perimeter fall or falls through the roof. Second they were categorized further into “falls through skylights”, falls through roof openings”, and falls through fragile materials”. Only the falls through the skylight in place (glass, fiberglass, plastic) were counted as falls through the skylight.

In their results, Suruda, et. al., reported 1695 work related falls in three years of which 288 (17%) were from roofs, and only one of them was female. The victims’ average age was 38.7 years. Out of 288 deaths; 232 were construction workers. According to the SIC codes, SIC 17, special trade contractors; and 172 within 17, roofing and structural steel erection had the highest fatality rates.

When the death certificates were matched out of the 288 fatal cases only 138 had complete OSHA report, and only 112 of them contained issued citations.

Location of the fall was reported according to the category described, and was available only in 163 cases. 70 of the fatal falls were from roof perimeter; edge or parapet and 93 of them were through the roof structure; and in 125 fall accidents there were no details available.

Out of the 288, fall height information was available in 148 cases. One third of the reported height cases were from 30 feet or less (3 stories or less) need adequate fall protection.

The authors affirmed the OSHA regulations, including: 1. Railing, guarding the skylights; 2. PPE wearing, making it the responsibility of the employer, 3.Using passive protections such as safety nets, fixed covers, catch platforms. 4. Using motion-stopping systems for the unprotected sides or edges of the roofs, 5. Training all roofers about the fall hazards. They also recommended full protection on pitched roofs such as anchor or tie point, safety belts and lanyards.

This paper did not look at the role of the environmental factors such as wind, rain or slippery surfaces underfoot. They did not determine the work experience from OSHA reports; the length of the worker's stay on the roof is unknown. Supervisors' attitude towards safe work practices and workers' beliefs that safe work habits decrease productivity may be contributing factors, but these could not be determined.

In summary, this paper used two data sets (death certificates and OSHA reports) combined to have a general descriptive analysis of fatal falls from the roofs. This study did not have any details on the availability of PPE, usage, personal experience, and environmental factors.

P. Kines (2001), focused on the Danish construction industry's male, fatal and serious injury causing fall from elevation accidents between the years 1993 and 1999. He tried to determine if the risk factors for fatal and nonfatal but serious injuries were the same. He used descriptive statistics on 20 selected cases that occurred on slanted roofs. According to Kines's findings, risk factors for fatal and nonfatal accidents differ by location (urban/non-urban), time of the day, and PPE use. The study found that most of the fatal accidents occurred at non-urban locations, during afternoon hours, and due to the lack of PPE usage. However, it was suggested that non- fatal serious injuries do occur in urban locations, in the afternoon hours, and while the workers are using PPE. Nevertheless, this study clearly indicates that the Danish construction industry needs to train their non-urban located construction workers on PPE usage.

Sa, et.al., (2009) compared the residential roofers to commercial roofers in terms of worker behavior, belief, work conditions, and attitudes towards the use of fall protection devices which could lead to fall accidents. They did surveys on 252 roofers in the Midwest. While preparing the surveys they benefited from the BLS statistics. Authors administered frequency analysis for frequencies and log binominal regression analysis to examine prevalence ratios (This type of statistical analysis is mostly used on surveyed data) and reported results within the 95% confidence interval (CI). Authors investigated the demographic characteristics, nature of injuries, fall protection provisions and the causes of falls. According to the findings, residential roofers were more prone to fall compared to commercial roofers; roofers who were working at the small companies (less than 11 workers) inclined to have more accidents than larger companies. This result was also in line with the findings of Chia et al, (2005). Sa et. al. also stated that falls from roofs were more likely to be occurring at heights lower than 20 feet. One interesting demographic fact that came out of this study was that minority workers were more likely to fall from roof than white workers. This finding is also supported by another study which is done by Brunette (2004) on Hispanic worker injuries at construction site. These findings clearly warn the residential roofing industry about protecting the minority employees.

Stern, et. al. (2000), evaluated causes of mortality among 11,144 members of the United Union of Roofers, Water Proofers, and Allied Workers (UURWAW). It is pointed out by the authors that the U.S. roofing industry, including both roofing and waterproofing applications, unionized and nonunionized, comprises about 25,000 firms, employing approximately 300,000 people, and about 200,000 of these are involved in the application of roofs.

Age-adjusted proportionate mortality ratios (PMRs) were computed with 95% confidence intervals (CI) using U.S. age-, gender-, and race-specific proportional mortality rates for the years of the study, 1950 through 1996.The authors used the death benefits file maintained by the UURWAW and they found statistically significant increases for PMRs for all injuries. Specifically, falls showed a PMR of 464 within a confidence interval from 419 to 513.

The most notable mortality risk among roofers documented in the study was due to falls, for where the PMR was significantly elevated reaching almost five times of that expected. For roofers younger than 65 at death, the PMR for falls from a building was 3442, which is over 34 times higher than expected.

This study is important in providing epidemiologic information about the deaths of roofers from all causes, and among these causes, falls constitute an important amount. The weakness of the study is that it does not include any information about workers who stopped paying their dues.

Authors do not have any new recommendations but they point out the preventative efforts of the “roofing industry coalition” and also mention the “Roofing Industry Partnership Program for Safety and Health''. The organizations that have agreed to support and participate in this pilot program are: OSHA, The National Roofing Contractors Association (NRCA), the UURWAW, CNA Insurance Companies, and the National Safety Council. It was indicated that the pilot program might recommend more intensive health and safety programs for roofers and their employers.

Ellis and Warner (1996) focused on promoting safety awards to prevent fall accidents. They not only recommended strong and consistent fall protection training programs, but also emphasized the importance of safety rewards on workers’ safety. They suggested the ongoing recognition of successful performance. This, however, may contradict with Sawacha, et. al.'s (1999) paper, which suggests that the productivity bonuses may cause the workers to act unsafe in order to achieve higher production.

Winn, et. al. (2004) recognized that fall fatalities are number one among all the construction incidents. They studied the literature in terms of the incentives' role on fall prevention. Based on their literature review and field questionaries' on workers, they found out that monetary incentives might have preventive effects. In addition, in their six month of field survey, they observed that the monetary incentives had very short life, such as a few days, on worker safety performance. They reported that non- material (natural) incentives such as performance feedback, employee determined work schedule, and independent work have longer term positive effects on fall safety performance. Nevertheless, the nature of the construction work schedule may not allow implementation of non-material incentives all the time.

Cohen and Lin (1991) focused on general ladder fall accidents on their research. They stated that fall from the ladder accidents which resulted in hospital emergency room admissions (nonfatal) were the second source of fall from elevation injury. They administered 123 after the fact fall accident interviews with the victims for an 18 month period. They coded the collected data by accident scenarios. According to their frequency analysis, they found that 60% of the accidents occurred while the workers were standing on the ladder; 26% were while they were descending from the ladder; and 14% occurred while ascending from the ladder. The activities that were frequently performed by the victims were 50% building maintenance and building construction, which shows the importance of ladder fall hazards in the construction industry. Overreaching while on the ladder was the highest frequency accident action. Their recommendations to industry were: (1) recognize the ladder as a hazardous item and limit the usage by replacing scaffolding and elevated platforms if possible; (2) apply regular ladder maintenance checks, and train the workers on ladder hazards.

This research supports the notion of the building construction and maintenance work being a significant part of falls from elevation, even though it has limitations on the study of accident causing factors.

Irizarry, et. al. (2005) stated that according to BLS (2002) records, 63% of the steel erection fatalities were due to falls. In this study the authors directly observed the steel erection activities and recorded the task durations. Authors used ANOVA to analyze the average task duration of the steel erection activities. Among the 186 observations on 3 projects over a 6 month period they found that use of PPE , the time of the day (morning or afternoon) the elevation that the work needed to be performed, and the presence of decking under the work area had significant effect on task durations. The authors' statistical analyses (ANOVA tests) showed that task duration was increased 1.3 times when PPE were used. Authors advise developing and using new PPE's with more mobility so the task duration does not increase. Authors also showed that the task duration increases when decking is installed on the lower level and task durations get longer in the morning hours than afternoon hours. This research shows that the environmental and safety factors increase the duration of the position , connect and unhook tasks, but when it is looked from total cycle time this can be considered minimal.

Benjaoran and Bhokha's (2010) study had an emphasis on integrated safety management by using a 4D CAD model. They formulated rule-based algorithms for hazards for working at heights. They identified the specific hazards and developed a system recommending the safety measures, such as safety precautions or requirements. These algorithms and safety measures were embedded in the 4D CAD model, so that each activity could be examined to determine if it contained hazards associated with working at-heights. The system helps to identify hazards during design and planning phases of construction projects, so safety measures can be easily incorporated in the schedule.

Beavers, et. al., (2009) reported on fatality cases in steel erection during the years 2000 through 2005. The authors analyzed OSHA's IMIS data. Authors are part of the Construction Industry Research and Policy Center (CIRPC) at the University of Tennessee. This center, under contract with OSHA's Directorate of Construction and Directorate of Evaluation and Analysis, Office of Statistical Analysis, has been evaluating the electronic records of these fatalities, which are available in the Agency's Integrated Management Information System (IMIS).

Based on its analysis of the IMIS records, CIRPC developed a mutually exclusive list of 29 proximal cause codes of all fatal construction events. Each fatal event occurring during the 16-year study period was classified and ranked by proximal cause and annual reports were submitted to OSHA (CIRPC 1993).

According to this study "fall from/ through roof" was the number one cause in terms of frequency, followed in rank order by "fall from/with structure (other than roof)," "crushed/run-over of non-operator by operating construction equipment," "electric shock by equipment contacting power source," and "hit, crushed, fall during lifting operations." These rankings have remained highly invariant from year to year. The five leading proximal causes encompassed approximately 40% of the fatal construction events inspected by OSHA Compliance Safety Health Officers throughout the nation from 1991 to 2006.

This paper concentrated on the fatalities involved in steel erections and falls were the leading cause with 125 (75.3%) of the 166 fatal events. The authors critically reviewed data from 166 steel-erection fatal events in the construction industry from 2000 to 2005 investigated by OSHA in the Federal Program States. The authors state their primary purpose as “to determine what safety practices need to be improved in steel erection.” Their key findings are as follows:

1. “Falls” dominated both steel decking and structural erection as the proximal cause; 2. The leading factor contributing to the cause “falls” were “lack of fall protection” and “fall protection not secured;” 3. The primary operation where the fatalities happened was the construction operation “structural erection”; 4. “Placement of steel decking,” was also a major source of fatalities; 5. Commercial building construction had the greatest number of fatalities; 6.The victim’s own actions dominated the initiation of the fatal event; 7. Most of the weaknesses in Safety and Health (SH) programs were in enforcement, safety training, and communication with employees; 8. 73.2 % of the victims were working at their task when the fatality occurred; 9. The action of the victim was responsible for two thirds of the fatalities; 10. The dominant violations of OSHA standards were failure to communicate safe work practices and to provide adequate fall protection.

Authors’ recommendations were as follows: data enhancement by accurate and complete data entry; and also data would help in developing intervention strategies.

This study also shows the lack of communication to employees so the obvious recommendation is for employers to communicate safety requirements to the employees and to have safety meetings during the construction process.

Also, the authors have shown in this study that the lack of fall protection was a major cause of fatalities during the steel-erection process; and they recommend a “safety person” who is present in the construction site at all times. This “competent” person would make sure there is personal fall protection equipment available and appropriate fall protection systems such as: guard rails, covers, nets, barriers, and safety nets.

The authors also recommend that the employers should pay special attention on fall protection standards and training of employees to understand fall protection standards.

The literature review presented herein reveals that numerous studies have been conducted on construction fall accidents to date by using either OSHA reports and data, or similar foreign organization accident reports. Some researchers have conducted surveys. The authors of these studies have mostly used univariate analysis, and a limited number of studies adopted the multivariate analysis methodologies such as analysis of variance (ANOVA), chi-square tests and binominal regression analysis. The most recently published study on fall- related accidents recorded by OSHA covered the years 1982 through 2002, and focused on all construction trades as a whole. In this dissertation research study, univariate and multivariate analysis of fall-related accidents recorded by OSHA between 1994 and 2008 were used. Our study specifically focused on Standard Industrial Classification (SIC) Codes 1761 and 1791, which are roofing, siding and sheet metal workers and structural steel erection workers.

As the methodology, three different types of analysis were carried out in this study. First, univariate analysis was used, starting with the identification of variables and generating univariate frequency values and percentages. Secondly, we obtained the relationships between dependent and independent variables by cross tabulation and used the chi-square test and phi values to determine the significance of the relationships and their strengths. Lastly, the identified variables were used to develop predictive models by utilizing logistic regression analysis.

Dichotomous categorical variables were used to first create a model for whole (combined) data. Second, separate models were developed for roofers (SIC1761) and for steel workers (SIC 1791). No published information has been encountered in the literature that has utilized this type comparative modeling approach. A detailed explanation of this approach is explained in the methodology part of this dissertation, followed by results and conclusions.

CHAPTER 3

METHODOLOGY

3.1. DATA SOURCE AND DATA ACQUISITION

The data source for this research project is OSHA's IMIS (Integrated Management Information System) database containing recordable incident reports filed for the time period of 1994 through 2008. Reports on all of the construction accidents included in this database are publicly available, and detailed information on accidents can be retrieved from OSHA's web page (www.osha.gov). A sample accident report is provided in Appendix A.

The data pertaining to SIC codes 1761 and 1791 were extracted from the OSHA database by OSHA staff using appropriate filters. Secondary filtering was applied by the researcher to obtain the data on fall from elevation cases.

The data initially provided to us by OSHA upon our request included the following categories: summary number; the date (day, month and year) of the accident; state in which the accident occurred; SIC code of the victim, union status; degree of injury; nature of injury; age of the victim; sex of the victim; event description; environmental factors; human factors; task regularity; event type; construction end use; project type; project cost; non-building height; fall distance; fall height; construction operation cause and fatality cause. OSHA's definitions of these terms appear in Appendix B. It should be noted that only data pertaining to SIC codes 1761 and 1791 was requested and received from OSHA.

Among the 2464 cases that were initially screened out, there were 253 cases that had insufficient or unclear information on the construction operation that led to the accident. Age and sex information were missing on 1155 cases and 169 cases lacked information on construction end use. Similarly, information on project type, project cost and fall distance were missing on 251, 259 and 40 cases, respectively. Finally, 701 cases for steel workers 1413 cases for roofers were determined to be complete and useable for statistical analysis.

3.1.1. OSHA DATA TAXONOMY

The information provided by OSHA was represented by the following taxonomy for categorical variables and their values, which were considered as a starting point for constructing the final research database. Table 3 presents a listing of these variables and their values, including the coding used by OSHA.

Table 3: Original OSHA variables

VARIABLE	VALUES
Day	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
Month	January, February, March, April, May, June, July, August, September, October, November, December
Year	1994-2008
State	All 50 states and territories
SIC code	1761 and 1791
Union status	Union Nonunion
Degree of injury	1.Fatality 2.Hospitalized 3.Non-hospitalized

Age	16 years old and over
Sex	1.Male 2.Female
Nature of the injury	1. Amputation 2. Asphyxia 3. Bruise/contus/abras 4. Burn(chemical) 5. Burn/scald(heat) 6. Concussion 7. Cut/laceration 8. Dermatitis 9. Dislocation 10.Electric shock 11.Foreign body eye 12.Fracture 13.Freezing/frost bite 14.Hearing loss 15.Heat exhaustion 16.Hernia 17.Poisoning(systemic) 18.Puncture 19.Radiation effects 20.Stra/spra 21.Other 22.Cancer
Environmental factors	1. Pinch Point Action 2. Catch Point/Puncture Action 3. Shear Point Action 4. Squeeze Point Action 5. Flying Object Action 6. Overhead Moving/Falling Obj Ac 7. Gas/Vapor/Mist/Fume/Smoke/Dust 8. Materials Handlg Equip./Method 9. Chemical Action/Reaction Expos 10.Flammable Liq/Solid Exposure 11.Temperature +/- Tolerance Lev. 12.Radiation Condition 13.Work-Surface/Facil-Layout Cond 14.Illumination 15.Overpressure/Underpressure 16.Sound Level 17.Weather, Earthquake, Etc. 18.Other

Human factors	1. Misjudgment, Haz. Situation 2. No Personal Protective Eq Used 3. No Appropr Protective Clothing 4. Malfunc In Securing/Warning Op 5. Distracting Actions By Others 6. Equip. Inappropr For Operation 7. Malfunc, Neuromuscular System 8. Perception Malfunc, Task-Envir. 9. Safety Devices Removed/Inoper. 10.Position Inapropriate For Task 11.Mater-Handlg Proced. Inappropr 12.Defective Equipment In Use 13.Lockout/Tagout Proced Malfunc 14.Other 15.Insuff/Lack/Housekeeping Program 16.Insuff/Lack/Expos/Biologcl Mntrg. 17.Insuff/Lack/Engineerng Controls 18.Insuff/Lack/Writn Wrk Prac Prog. 19.Insuff/Lack/Respiratory Proctect 20.Insuf/Lack/Protcv Wrk Clthg/Equip
Task	1.Regularly assigned 2.Not regularly assigned
Event type	1. Struck by 2. Caught in or between 3. Bite/sting/scratch 4. Fall (same level) 5. Fall (from elevation) 6. Struck against 7. Rubbed/abraded 8. Inhalation 9. Ingestion 10.Absorption 11.Rep. Motion/pressure 12.Card-vasc./resp. fail. 13.Shock 14.Other

Construction end use	1. Single family or duplex dwelling 2. Multi-family dwelling 3. Commercial building 4. Manufacturing plant 5. Refinery 6. Power plant 7. Sewer/water treatment plant 8. Other building 9. Highway, road, street 10. Bridge 11. Tower, tank, storage ,elevator 12. Shoreline development, dam, reservoir 13. Pipeline 14. Excavation, landfill 15. Power line, transmission line 16. Other heavy construction 17. Contractor's yard/facility
Project type	1. New project or new addition 2. Alteration or rehabilitation 3. Maintenance or repair 4. Demolition 5. Other
Project cost	1. UNDER $50K 2. $50-$250K 3. $250-$500K 4. $500K-$1M 5. $1-$5M 6. $5-$20M 7. $20 M over
Non building height	Nearest whole number
Fall height	Nearest whole number
Fall distance	Nearest whole number

Construction operation cause	1. Back filling and compacting 2. Bituminous concrete pavement 3. Construction of playing fields and tennis courts 4. Cutting concrete pavement 5. Demolition 6. Not Applicable 7. Elevator/ escalator installation 8. Emplacing reinforcing steel 9. Erecting structural steel 10. Not Applicable 11. Excavation 12. Exterior masonry 13. Exterior cladding 14. Exterior carpentry 15. Exterior painting 16. Fencing, installing lights, signs etc. 17. Not Applicable 18. Forming 19. Forming for piers and pylons 20. Installing interior walls ceilings and doors 21. Installing metal siding 22. Installing windows doors and glazing 23. Installing culverts and incidental drainage 24. Installing equipment (HVAC other) 25. Installing plumbing , lighting fixtures 26. Not Applicable 27. Interior tile work (ceramic, vinyl , acoustic) 28. Not Applicable 29. Interior plumbing, ducting, electrical work 30. Interior carpentry 31. Exterior carpentry 32. Landscaping 33. Not Applicable 34. Not Applicable 35. Not Applicable 36. Placing bridge deck 37. Placing bridge girders and beams 38. Plastering 39. Pouring or installing floor decks 40. Pouring concrete floor at grade 41. Not Applicable 42. Pouring concrete foundation and walls 43. Roofing 44. Not Applicable 45. Site clearing and grubbing 46. Not Applicable 47. Not Applicable 48. Surveying 49. Not Applicable 50. Temporary work (buildings, facilities) 51. Not Applicable

	52. Trenching, installing pipe 53. Waterproofing 54. Steel erection of solid web -connecting 55. Steel erection of solid web – bolting – up /detail work 56. Steel erection of solid web –welding /burning/grinding 57. Steel erection of solid web-plumbing-up. 58. Steel erection of solid web-moving point to point. 59. Steel erection of solid web-landing materials (hoisting) 60. Steel erection of open web steel joists-connecting 61. Steel erection of open web steel joists-bolting-up 62. Steel erection of open web steel joists-welding 63. Steel erection of open web steel joists-plumbing 64. Steel erection of open web steel joists-moving point to point 65. Steel erection of open web steel joists-landing materials 66. Installation of decking-initial laying deck 67. Installation of decking-final attachment deck (welding) 68. Installation of decking-flashing of decking 69. Installation of decking-hoisting bundles 70. Other activities-installing ornamental and archite 71. Other activities-post decking detail work
Fatality cause	1. Asphyxiation / inhalation of toxic vapor 2. Caught in stationary equipment 3. Collapse of structure 4. Crushed/run over of non-operator by operating cons. 5. Crushed/run over/trapped of operator by operating cons. 6. Crushed/run over by construction equipment during 7. Crushed/run over by highway vehicle 8. Electrocution by touching exposed wire/source 9. Electrocution by equipment contacting wire 10. Electrocution from equipment installation / tool use 11. Electric shock, other and unknown cause 12. Drown, non-lethal fall 13. Elevator (struck by elevator or counter weights) 14. Fall from/with ladder 15. Fall from roof 16. Fall from/with scaffold 17. Fall from/ with bucket (aerial lift basket) 18. Fall from/ with structure other than roof 19. Fall from / with platform catwalk (attached to structure) 20. Fall through opening (other than roof) 21. Fall other 22. Fall from vehicle 23. Fire/ explosion 24. Heat / hypothermia 25. Lifting operations 26. Struck by falling object/ projectile 27. Not Applicable 28. Unloading/ loading equipment/ material (except by crane) 29. Wall (earthen) collapse 30 Other

3.1.2. DATA REFINEMENT

The taxonomy used by OSHA and presented in Table 3 was subsequently modified; some variables were eliminated if they appeared to be not useful or relevant; and new variables were created by reviewing the 2114 case reports to produce potentially more useful and relevant variables. Also, some of the OSHA variables and values were renamed to improve their ease of understanding in terms of practical construction situations. For example, the "construction operation cause" name was changed to "construction operation that prompted fall" to describe it better; and "fatality cause" similarly was changed to "fatality/injury cause" because it contained both fatality and injury cases. As a result, an initial version of the research database was created with the variables and values listed in Table 4.

Table 4: Initial research data taxonomy

Variables	Values
1. Union status	Union Nonunion
2. Degree of injury	Fatal Nonfatal
3. Age	**AG1**:15-25: **AG4**: 46-55 **AG2**:26-35: **AG5**: 56-65 **AG3**:36-45: **AG6**: 66 over
4. SIC code	1761 1791
5. Environmental factors	Same as OSHA taxonomy
6. Human factors	Same as OSHA taxonomy
7. Task assignment	Same as OSHA taxonomy
8. Construction end use	**CEG1**: Highway **CEG5**: Other **CEG2**: Heavy/civil **CEG6**: Industrial **CEG3**: Residential **CEG4**: Commercial

9. Project type	**PT 1:** New project or new addition **PT 2:** Alteration/rehabilitation, maintenance/repair, demolition and other.
10. Project cost	**PC 1**: less than $50K **PC 2**: more than $50K less than $5M **PC 3**: more than 5M
11. Fall distance	**FD 1**: 0-10 feet **FD 2**: more than 10' less than 20' **FD 3**: more than 20'
12. Construction operation prompting fall	Same as OSHA taxonomy
13. Fatality/ injury cause	Same as OSHA taxonomy

It was noted that the variable work surface/facility layout condition was the highest occurring environmental factor (1175 cases) causing the accidents, while the term was somewhat ambiguous. So, a secondary review was performed on the mentioned cases under this category to further identify subcategories of this variable. These subcategories are as follows:

1. Hazardous work surface/ housekeeping problems
2. Structural failure (other than full collapse)
3. Unguarded/ improperly secured platforms, walkways, openings edges, ladders
4. Moving, flying or falling object
5. Wind and other weather related factors
6. Materials handling and equipment
7. Chemical and radiation action
8. Miscellaneous issues of work service facility layout conditions.
9. Other

The values of variables for age, human factors, construction end use, construction operation prompting fall, fatality/injury cause were also re-organized. The cases that had frequencies less than 5% were bulked together to form the final set of values. On a separate effort, citation information was reviewed for each case and three new variables were created. These three new categorical variables were named fall safety system provided, fall safety system used, and safety training provided. The final form of the research data taxonomy is displayed in Table 5.

Table 5: Final research data taxonomy

Variables	Values
1. Degree of injury	1. Fatal 0. Nonfatal
2. Union status	1. Union 0. Nonunion
3. Age	1. **AG 1**≤30 years old 2. 30<**AG 2**< 50 3. **AG 3**≥50
4. SIC Code	1. 1761- roofers 0. 1791-steel workers
5. Environmental factors	1. Hazardous work surface/ housekeeping problems 2. Structural failure (other than full collapse) 3. Unguarded/ improperly secured platforms, walkways, openings edges, ladders 4. Moving flying or falling object 5. Wind and other weather related factors 6. Materials handling and equipment 7. Chemical and radiation action 8. Miscellaneous issues of work service facility layout conditions. 9. Other

6. Human factors	1. Misjudgment of hazardous situation 2. Malfunctioning safety equipment/system (including lockout /logout tag out) 3. Distracting actions by others 4. Human system malfunction 5. Inappropriate choice /use of equipment, position, material handling, processing 6. Insufficient engineering and administrative controls 7. Other
7. Task regularity	1. Regularly assigned 0. Non regularly assigned
8. Construction end use	**CEG 1**: Commercial and residential **CEG 2**: Industrial **CEG 3**: Heavy civil **CEG 4**: Other
9. Project type	**PT 1**: New project or new addition **PT 2**: Alteration or rehabilitation, maintenance or repair, demolition and other.
10. Project cost	**PC 1**: less than $50K **PC 2**: more than $50K less than $5M **PC 3**: more than 5M
11. Fall distance	**FD 1**: 0-10 feet **FD 2**: more than 10’ less than 20’ **FD 3**: more than 20’

12. Construction operation prompting fall	1. Roofing 2. Erecting structural steel 3. Ext carpentry, 4. Installing metal siding & water proofing 5. Specific steel functions including decking 6. Other
13. Fatality/injury cause	1. Collapse of structure 2. Fall from /with ladder 3. Fall from roof 4. Fall from / with scaffold, bucket and platform catwalk (attached to the structure) 5. Fall through opening 6. Fall from /with structure other than roof 7. Other
14. Fall safety protection system provided (including proper cover and defective equipment, e.g. ladder, scaffold)	1: Provided 0: Not provided
15. Fall safety protection system is used	1: Used 0: Not used
16. Safety training and re-training provided	1: provided 0: not provided

3.2. STATISTICAL ANALYSIS

3.2.1. UNIVARIATE FREQUENCY ANALYSIS

Frequency distributions were established for the variables listed in Table 5 to observe the magnitudes of the values pertaining to each variable. The SPSS software was used for this analysis. The results, first for the whole data (2114 cases for SIC 1761 and 1791 combined), then for roofers (1413 cases for SIC code 1761), and lastly for steel workers (701 cases for SIC 1791) were graphed and presented in the form of bar charts.

3.2.2. MULTIVARIATE ANALYSIS

In this study, multivariate analysis were performed on the whole data (combined SIC 1761 and SIC 1791), and then separately on SIC 1761 (roofer) and SIC 1791 (steel worker) data. Cross tabulation was done to study the relationship between the research variables. For this purpose, each variable's effect on the degree of injury was examined. The consequences of the accidents were divided into two categories; fatality, and non-fatality. This is the degree of injury variable, which comes from the original OSHA taxonomy. The degree of injury was adopted as the dependent variable, and all the other variables were taken as independent variables. In other words, the effects of the factors (independent variables) on the degree of injury (dependent variable) were investigated. The SPSS program was used for this analysis, as well.

3.2.2.1. CROSS TABULATION, CHI SQUARE VALUES AND PHI VALUE

In this portion of the study, cross tabulation was used to examine the frequencies of observations that belong to specific categories on two or more variables. By studying these frequencies, we can identify the relationships between the cross -tabulated variables. Cross tabbing was applicable, since most of the variables in this study were categorical. However, it is possible to convert continuous variables to categorical variables by recoding, and this was done, when needed.

The simplest form of cross tabulation is the 2 by 2 contingency table where two variables are "crossed," and each variable has only two distinct values. Each cell represents a unique combination of values of the two cross-tabulated values, and the numbers in each cell indicate how many observations fall into each combination of values. These observations are calculated simply by establishing the frequencies of variables from the data set. The relationship can be determined by using the Pearson chi square statistic or the maximum likelihood chi square statistic. The chi-squared test works on the hypothesis that the row and column classifications are independent. It displays the calculated test statistic and an associated p-value. If the p-value falls below a critical value such as 0.05, the hypothesis of independence between rows and columns is rejected at that significance level. The individual rows or columns of a cross-tab table can be represented graphically by using histograms, bar charts, or line plots.

The basic approach taken to select the variables for cross tab analysis was to consider the associations between the dependent variable and each of the independent variables. This is summarized in Table 6.

Layered cross tabulation determines the collective effect on degree of injury from two or more independent variables. Two layered cross tabulation analysis were done in this research study. First, if safety training and union status had any collective effect on fatality, second, SIC codes and union status' collective effect were determined.

Table 6: Cross tabulation summary

Independent Variables	Dependent variable
Union	Degree of injury
Sic	Degree of injury
Age	Degree of injury
Environmental factors	Degree of injury
Human factors	Degree of injury
Task assignment	Degree of injury
Construction end use	Degree of injury
Project type	Degree of injury
Project cost	Degree of injury
Fall distance	Degree of injury
Construction operation prompting fall	Degree of injury
Fatality/injury cause	Degree of injury
Fall safety protective system provided	Degree of injury
Fall safety protective system used	Degree of injury
Fall safety training provided	Degree of injury
Fall safety training provided and union status (layered)	Degree of injury
SIC Code and union status (layered)	Degree of injury

3.2.2.1.1 Parameters:

Pearson chi square (X^2) test is used to identify the significance of the relationship variables, while p denotes the significance of the chi square value.

The relevant formula is:

$$\mathbf{X^2} = \sum_{\mathbf{i=1}}^{\mathbf{N}} \frac{(\mathbf{O_i} - \mathbf{E_i})^2}{\mathbf{E_i}} \qquad \textit{Equation 1}$$

where $\mathbf{O_i}$ = Observed frequencies

$\mathbf{E_i}$ = Expected frequencies, and

$\mathbf{N}$ = Sample size

The "p-value" is used to determine whether or not the deviation of the observed from that expected is due to chance.

When the p-value is less than the significance value of 0.05, (α=.05, confidence level of 95%) the null hypothesis is rejected, and the result is said to be statistically significant.

Furthermore, to know the relative strength of this relationship, Phi or Cramer's values are calculated. Phi value is applicable to only 2x2 cross- tab tables, while Cramer's V has no restriction.

Phi and V are calculated by:

$$\emptyset = \sqrt{\frac{X^2}{N}} \qquad V = \sqrt{\frac{X^2}{m.N}} \qquad \textit{Equation 2}$$

m= (# rows-1) or (# columns-1), whichever is smaller

Phi values as well as Cramer's V values vary from 0 to 1.

In this study, we adopted the below scale for that Φ or Cramer's V values indicate the following:

- 0-.1 – weak relationship
- .1-.3 – moderate relationship; and
- .3-1.0 – strong relationship

(Healey, 2011)

The odd is the ratio of the probability that an event of interest occurs to the probability that it does not occur. This is often estimated by the ratio of the number of times that the event of interest occurs to the number of times that it does not. (M.Bland., and D.G. Altman, 2000).

$$\text{Odds}=\frac{P_1}{1-P_1} \qquad \textit{Equation 3}$$

Where, p_1= The probability of the occurrence of event 1.

$$\text{Odds ratio}=\frac{P_1/_{1-P_1}}{P_2/_{1-P_2}} \qquad \textit{Equation 4}$$

Where, P_2= The probability of the occurrence of event 2.

Events are dichotomous variables used in cross tabulation, V1, V2.

3.2.3. LOGISTIC REGRESSION MODELING

Logistic regression (LR) is a mathematical modeling approach which describes the occurrence or nonoccurrence of an event. This method has been used in epidemiological research for calculating the probabilities of certain disease outcomes; (Kleinbaum, 1994); traffic accident causal factor probabilities (Al –Ghamdi, A.S., 2002); and also in construction management (Huang, 2003). Like any other model building technique, the goal of the logistic regression analysis is to find the best fitting and most parsimonious, yet reasonable, model to describe the relationship between an outcome (dependent or response variable) and a set of independent (predictor or explanatory) variables (Hosmer and Lemeshow, 2000). Logistic regression does not have the requirements for the independent variables to be normally distributed, linearly related, or of equal variance within each group (Kleinbaum, et.al. 1994).

3.2.3.1. MODEL CONSTRUCTION

Logistic regression is useful for situations in which one wants to be able to predict the presence or absence of a characteristic (outcome variable) based on the values of a set of predictor variables. It is suited to models where the dependent (outcome) variable is categorical and dichotomous. Logistic regression coefficients can be used to estimate odds ratios for each of the independent (predictor) variables in the model. The predictor variables can be categorical or continuous. (SPSS version 20 definitions, user manual 2012).

Logistic regression is used for prediction of the probability of occurrence of an event by fitting data to a logit function curve. This function generates a cumulative distribution function of S shape (Figure 10) where the probability must lie between 0 and 1. It should be noted that the relationship between probability and the independent variables is nonlinear, but the relationship of the log odds and the independent variables is linear.

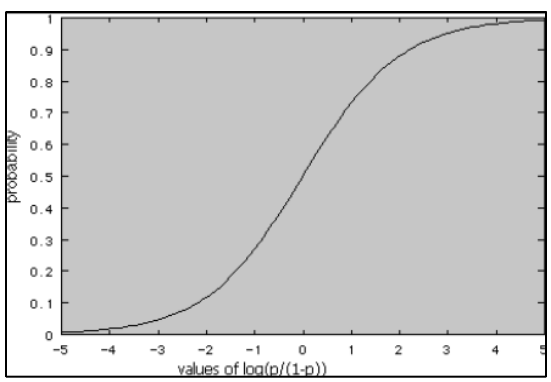

Figure 10: Logit function

In this study, logistic regression techniques are applied to determine how the probability of the degree of injury can be predicted from information contained in previous accident data. The relationship takes the form of an arithmetic equation;

$$Y = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \ldots + \beta_n.X_n \qquad \textit{Equation 5}$$

Where, Y = Degree of injury (dependent variable); β_0= exposure variable (or constant); $\beta_{1\ldots n}$ = regression coefficients; and $X_{1\ldots n}$= accident variables (independent/ input variables).

Y can also be written as:

$$Y = \beta_0 + \sum_{i=1}^{n}(\beta_i.X_i) \qquad \textit{Equation 6}$$

In the model $P(x)$ denotes the probability that $Y=1$, which is the occurrence of the fatal injury. Similarly, 1- $P(x)$ defines the probability that $Y=0$, which is the absence of fatal injury (or the existence of non-fatal injury). It should be mentioned that the x in the expression $P(x)$ is a vector representing the set of the independent predictor variables $X_1, X_2 \ldots Xn$. These probabilities can be written in the following form:

$$P(x) = P(Y = 1|\ X_1, X_2 \ldots X_n) \qquad \textit{Equation 7}$$

and

$$1 - P(x) = P(Y = 0|\ X_1, X_2 \ldots X_n) \qquad \textit{Equation 8}$$

Then the odds function can be expressed by using the logit transformation as:

$$\mathbf{ln}\left(\frac{\mathbf{P}\ (\mathbf{Y=1}|\mathbf{X_1,X_2,\ldots,X_n,})}{\mathbf{1-P(Y=1}|\mathbf{X_1,X_2,\ldots,X_n,})}\right) = \mathbf{ln}\left(\frac{\mathbf{P(x)}}{\mathbf{1-P(x)}}\right) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1.X_1} + \boldsymbol{\beta_2.X_2} + \cdots \boldsymbol{\beta_n.X_n} \qquad \textit{Equation 9}$$

or

$$\mathbf{ln}\left(\frac{\mathbf{P}\ (\mathbf{Y=1}|\mathbf{X_1,X_2,\ldots,X_n,})}{\mathbf{1-P(Y=1}|\mathbf{X_1,X_2,\ldots,X_n,})}\right) = \mathbf{ln}\left(\frac{\mathbf{P(x)}}{\mathbf{1-P(x)}}\right) = \boldsymbol{\beta_0} + \sum_{\mathbf{i=1}}^{\mathbf{n}}(\boldsymbol{\beta_i} \cdot \mathbf{X_i}) \qquad \textit{Equation 10}$$

For the purposes of this research, using the inverse of the logit transformation of the above equation one can arrive at the following equation:

$$P(Y=1|X_1, X_2 \ldots X_n) = \frac{\mathbf{1}}{\mathbf{1+e^{-(Y)}}}$$ *Equation 11*

where P indicates the occurrence of the fatal injury. And in the equation Y is used

for $\beta_0 + \sum_{i=1}^{n}(\beta_i . X_i)$

"Wald test" parameter is used to test the statistical significance of each coefficient (β) in the model. Coefficient beta (β) is also used to calculate exponential beta (EXP (β)) which is used as an odds ratio for each independent variable. This essentially is a probability of an event occurring vs. not occurring.

The SPSS program was used to develop the regression models. The Hosmer and Lemeshow test was used to measure of goodness of fit. It indicates a poor fit if the significance value is less than 0.05.

3.2.3.2. MODEL VALIDATION

Predictive logistic regression models are developed in this study to make informed decisions on the role of fall accident factors' on fatality. Before predictions from logistic regression models are attempted, predictive ability should be validated. Model validation can be checked by studying residuals, defined as the difference between predicted and observed outcome. Validation refers to the agreement of predicted and observed predictions, e.g. 70% predicted = 70% observed. There are three ways to validate the model. 1. Apparent: performance on the sample used to develop model; 2.Internal: performance on the population underlying the sample; 3.External: performance on a related but slightly different population.

In this study the internal validation technique was used. A key characteristic for internal validation is that data for model development and evaluation are both random samples from the same underlying population. (Steyerberg et.al. 2001)

The SPSS program uses simulated Bernoulli trials to draw a random sample of records from a finite population of records (Strand, 1979). This software randomly assigns cases to sample groups. In this study a 70/30 split of the data was adopted for validation. If the overall percentages of correct prediction values are close, this means the model is validated.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. UNIVARIATE FREQUENCY ANALYSIS OF WHOLE DATA

In the figures representing the results of the univariate frequency analysis, the number at the top of the bar denotes count, and the number in the middle is the corresponding percentage. This convention has been followed for Figures 11 through Figure 56, which cover all of the research variables used in this study. Note that, these figures have been designed to show the frequencies in descending order to facilitate easier identification of high, medium and low values.

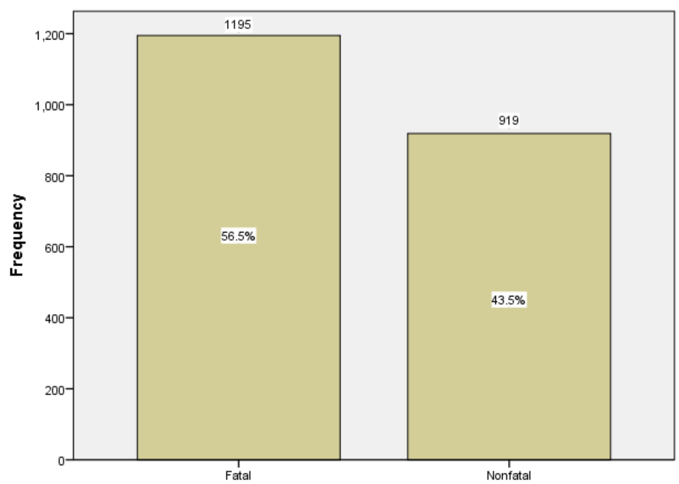

Figure 11: Frequency analysis for degree of injury

In reference to Figure 11, one can observe that the majority of the accidents (56.5%) included in the analysis resulted in fatality in comparison to (43.5%) which were nonfatal. These results show that the degree of injury is well balanced relative to the distribution of fatal versus nonfatal accidents.

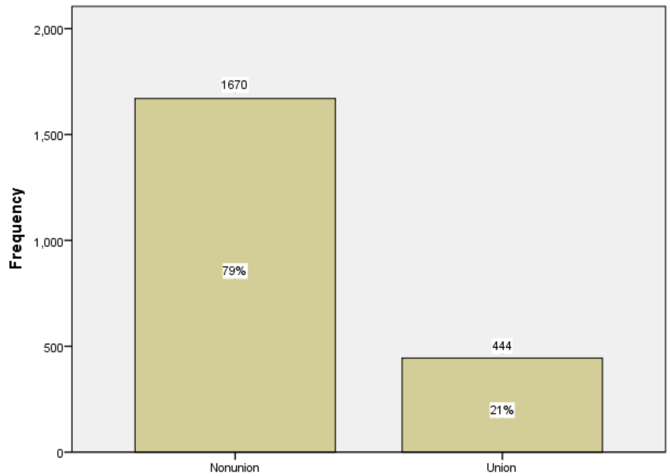

Figure 12: Frequency analysis for union status

The frequency analysis shown in Figure 12 indicates that most of the accident victims were nonunion members (79%).

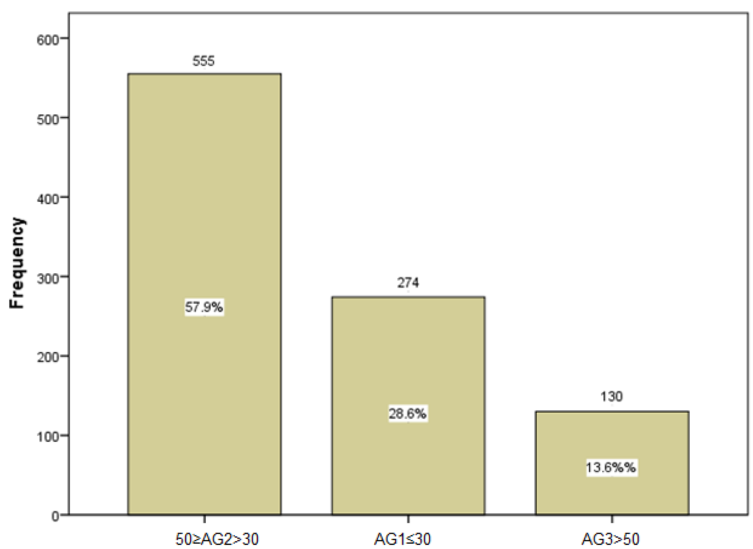

Figure 13: Frequency analysis for age

Age information was missing in 1155 cases, which represents more than fifty percent of the whole data. The univariate frequency anaysis performed on the remaining data clearly shows that age group 2 (50≥ **AG 2** >30) is the most accident prone age group, as can be seen from Figure 13. This observation is in line with the findings of Huang and Hinze (2003), except for the fact that they covered all construction trades. In a different study, however, Sawacha, et.al.(1996) identified the worker age group of 16 to 20 as the most accident prone, and further suggested that above the age of 28, accidents tended to decline. The authors tied this to experienced workers being more careful on the task site. In contrast, Huang and Hinze (2003) conculuded in their paper that experience in construction for more years may not necessarily lead to a decrease in fall accidents.

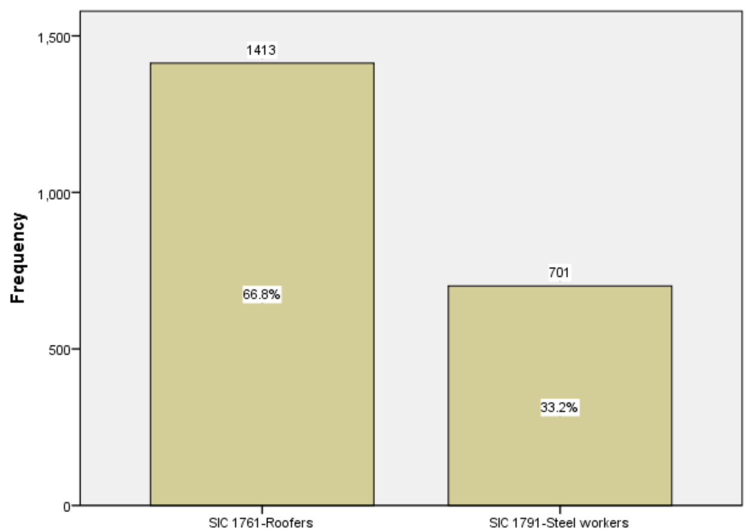

Figure 14: Frequency analysis for SIC Code

The univariate frequency analysis for the two SIC codes (roofers and steel workers) is shown in Figure 14, which indicates that the data is dominated by the roofers (66.8%) versus steel workers (33.2%). This signifies that roofing industry is more prone to accidents. Janicak (1998), stated in his paper that roofing is the most fatality prone trade among all others.

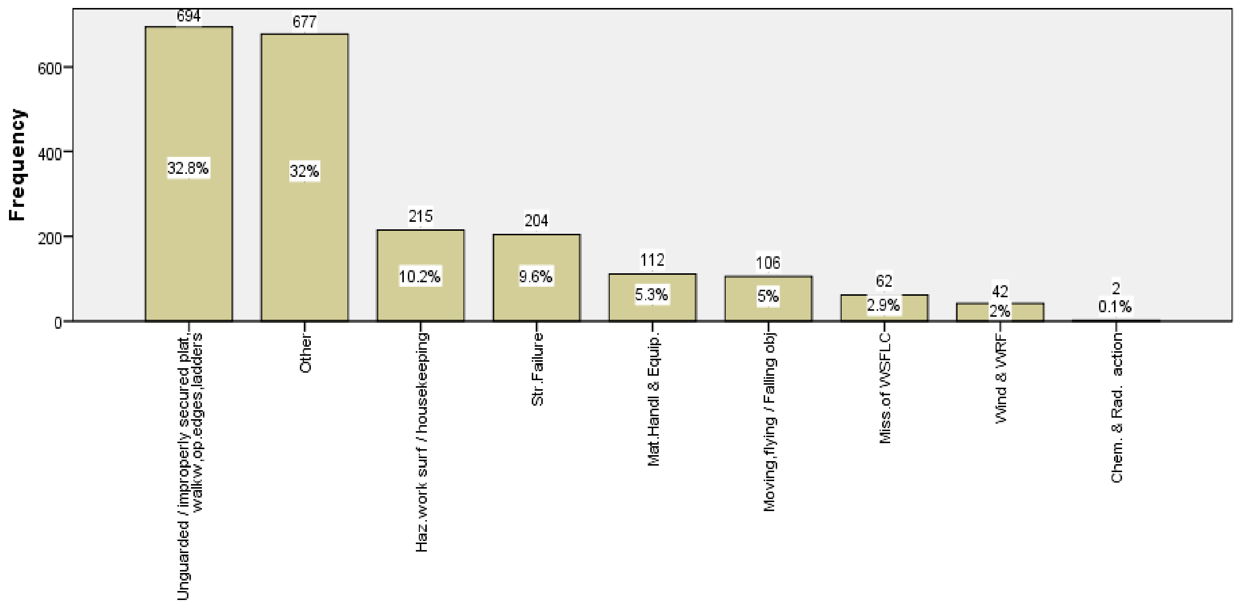

Figure 15: Frequency analysis for environmental factors

Figure 15 displays the frequencies of subfactors (values) under the environmental factor variable. It is clear that unguarded/improperly secured platforms, walkways, openings, edges and ladders have occurred most frequently, closely followed by the "other" category. This category includes pinch point action, catch point/ puncture action, squeeze point action, temperature +/- tolerance level, illumination, and overpressure/under pressure. Although in smaller frequencies, hazardous work surface/ housekeeping, structural failure, material handling and equipment and moving, flying/falling object, also play roles in accidents as considered under environmental factors.

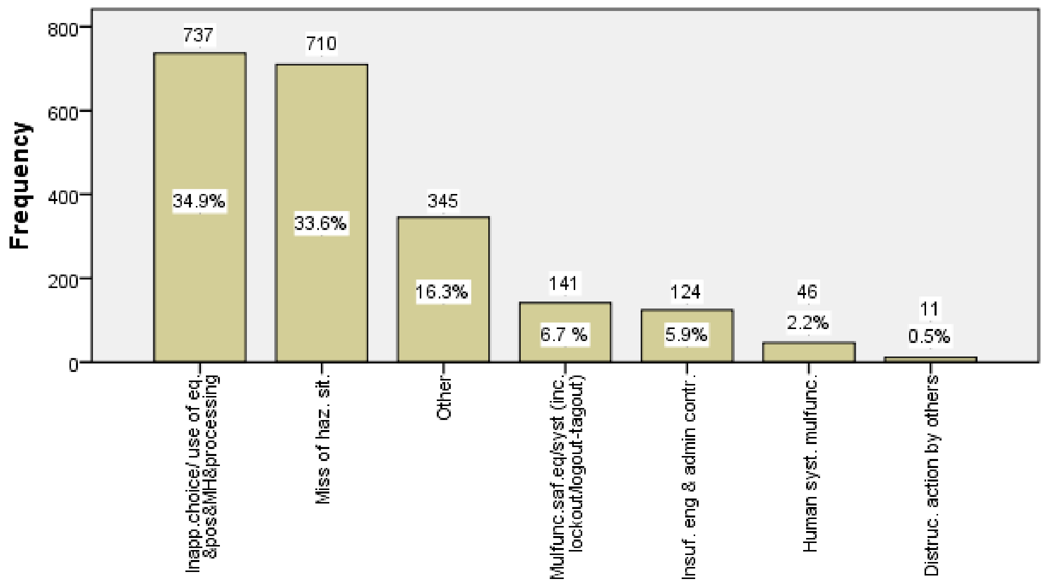

Figure 16: Frequency analysis for human factors

So far as human factors are considered, inappropriate choice/use of equipment, position, material handling, processing showed the highest frequencies, closely followed by misjudgment of hazardous situation. These are laid out in Figure 16. A report, based upon OSHA-inspected fatal events in construction during the calendar year of 2003, suggests that in 61.2% of the fatal accidents the victim was the primary initiator of the event, underscoring the importance of human element in accident causation. (Construction Industry and research policy at the University of Tennessee, Knoxville for OSHA's Office of statistics, 2003).

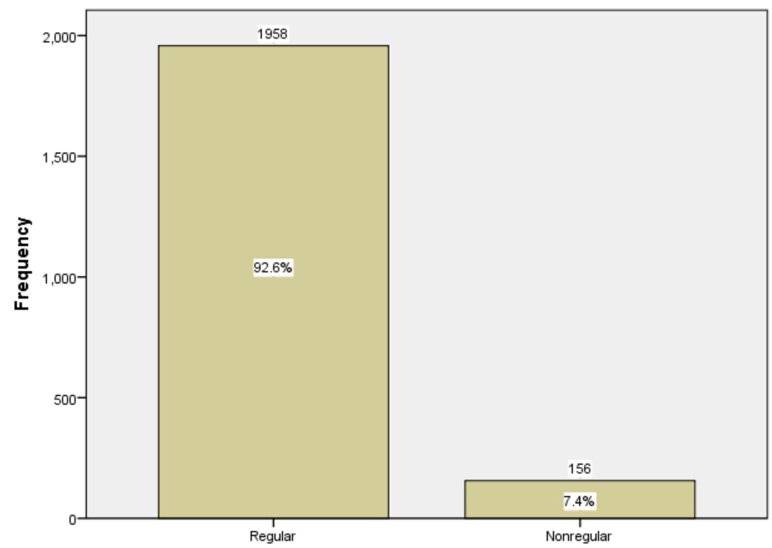

Figure 17: Frequency analysis for task regularity

Figure 17 shows that a majority of the fall from elevation accidents occurred while the victim was working on a regulary assigned task. Research done by Construction Industry Research and Policy Center, University of Tennesse , Knoxville (2003) confirms this finding. It was found in this study that in 72.3% of construction accidents, the victim was at his/her regulary assigned task.

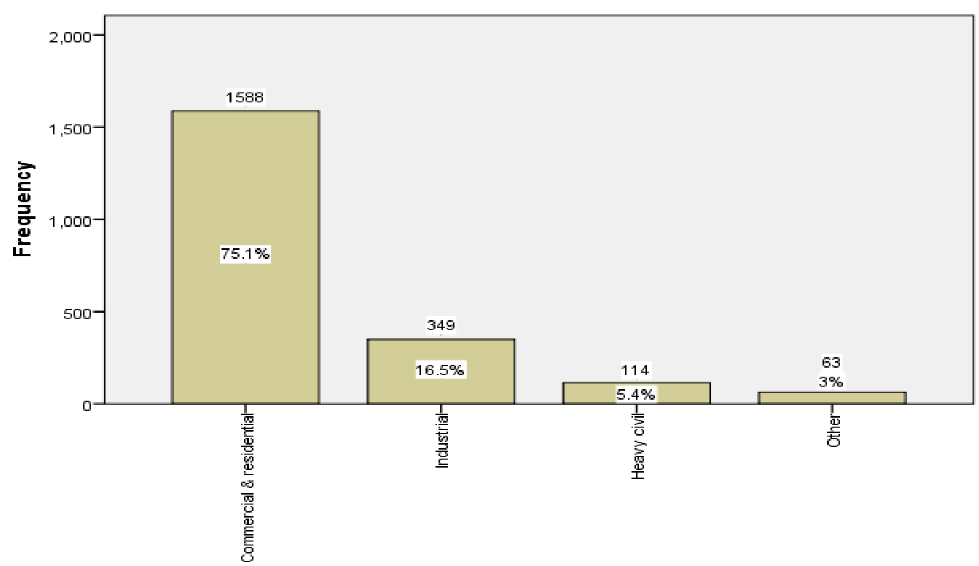

Figure 18: Frequency analysis for construction end use

Construction end use frequencies are graphed in Figure 18, where it is observed that commercial and residential work has the highest accident frequency. Prior to December 16, 2010, which is before the time period covering our resarch data, OSHA's standard 03-00-001 allowed employers, who were engaged in certain residential construction activities to, use alternative methods of fall protection that were specified to them rather than conventional fall protection required by the residential construction fall protection standard. But this was not effective. According to Assistant Secretary of Labor for Occupational Safety and Health, Dr. David Michaels (December 2010), "fatalities from falls are the number one cause of workplace deaths in construction and that there should be no tolerant attitude towards workers getting killed in residential construction accidents when there are effective means readily available to prevent their deaths". (http://www.hugsafety.com/2010/12/28/oshas-new-residential-roof-safety-directiv/). This new directive, which become effective on December 16, 2010, indicates that all residential construction employers must now comply with 29 Code of Federal Regulations 1926.501(b)(13). This may provide better fall protection to construction workers, especially residential roofers.

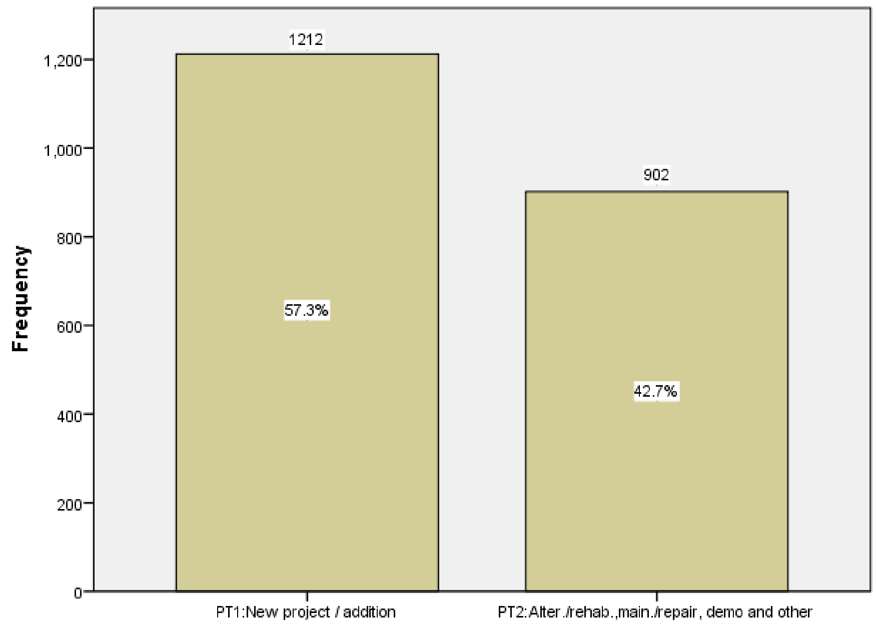

Figure 19: Frequency analysis for project type

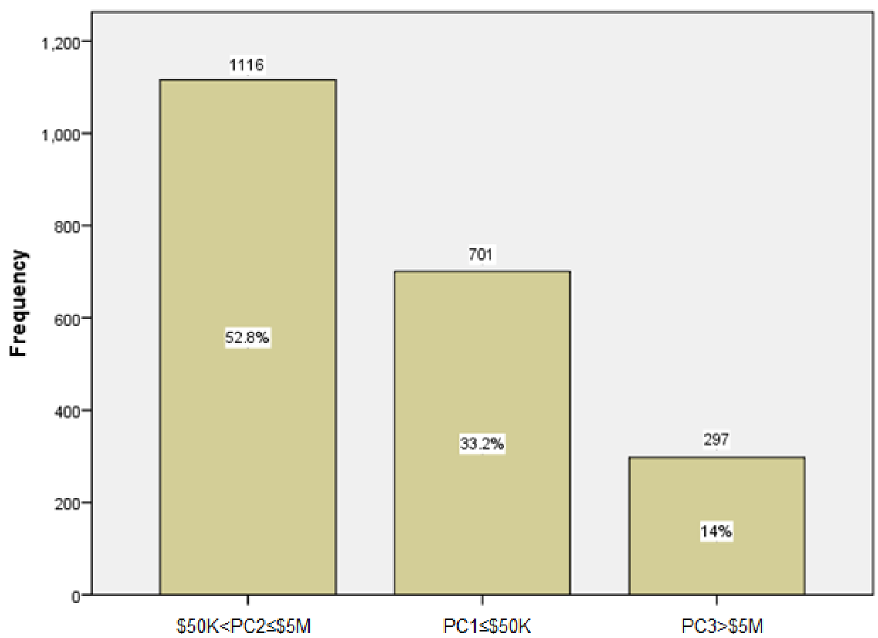

Figure 20: Frequency analysis for project cost

As seen in Figure 19 and 20, most of the accidents occurred in new projects or additions, and in projects costing between $50,000 and $ 5 million.

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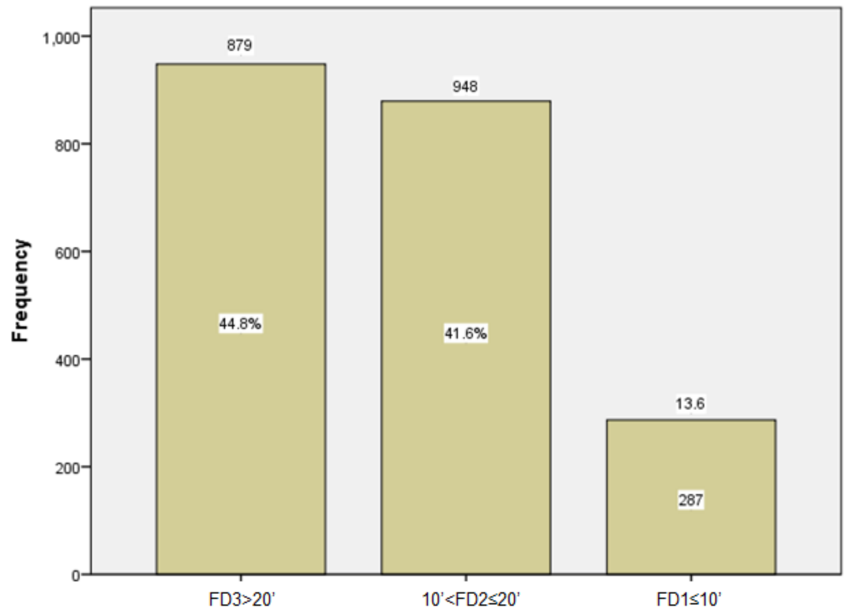


Figure 21: Frequency analysis for fall distance

Fall distance frequency analysis results are graphed in Figure 21. According to these results, most of the accidents occurred for fall distances over 20 feet. The mean fall distance for the whole data was 23.77 feet; the minimum fall height was 1 feet, and the maximum fall height was 339 feet. Analyses by Huang and Hinze (2003) identified the fall heights of 0 to 30 feet as the most frequently occurring in fall accidents for all construction workers. However, in the study by Janicak (1998) based on review of 565 OSHA accident cases between the years of 1992 and 1995, it was found that falls mostly occurred at work heights of 12 feet or less. This study may have included falls on the same level.

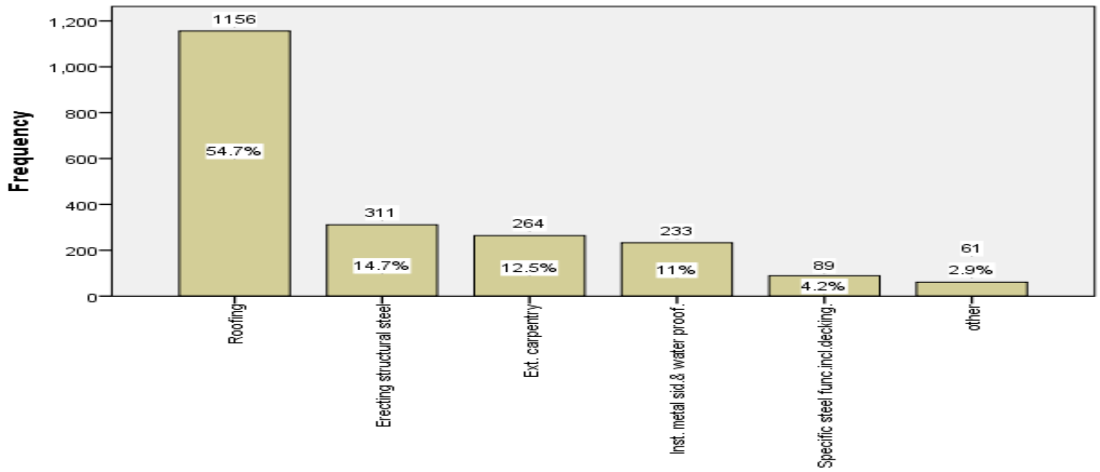


Figure 22: Frequency analysis for construction operation prompting fall

Figure 22 exhibits frequencies for the various construction operations prompting fall accidents. Here, roofing stands out as the dominating construction operation (54.7%) that leads to an accident. Others with relatively significant percentages are erecting structural steel, external carpentry, and installation of metal siding and water proofing.

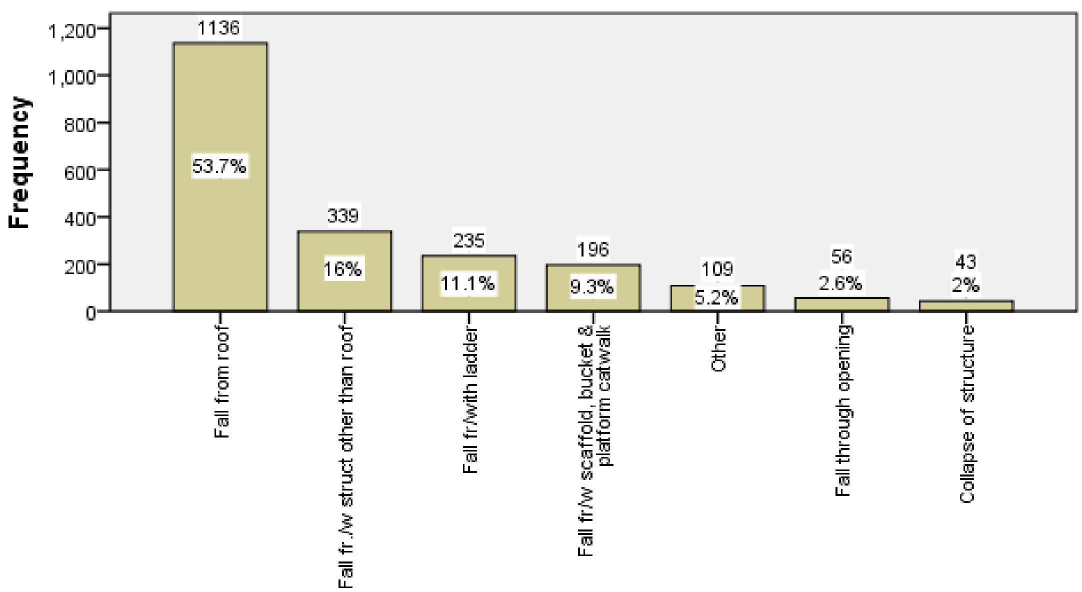


Figure 23: Frequency analysis for fatality/injury cause

Frequency values for fatality/injury cause are bar graphed in Figure 23, where fall from roof comes out as the most frequently occuring fatality/injury cause, at a level of 53.7%. Falls from/with structures, from/with ladders,and from/with scaffolds and similar platforms also show relatively high frequencies, but significantly below falls from roofs. The Construction Industry Research and Policy Center, University of Tennesse, Knoxville (2003) implemented univariate frequency analysis of 707 accidents that occurred in 2003 based on OSHA's accident reports. Their findings also support that fall from roof is the leading fatality cause, which is 10.7% of all fatal cases.

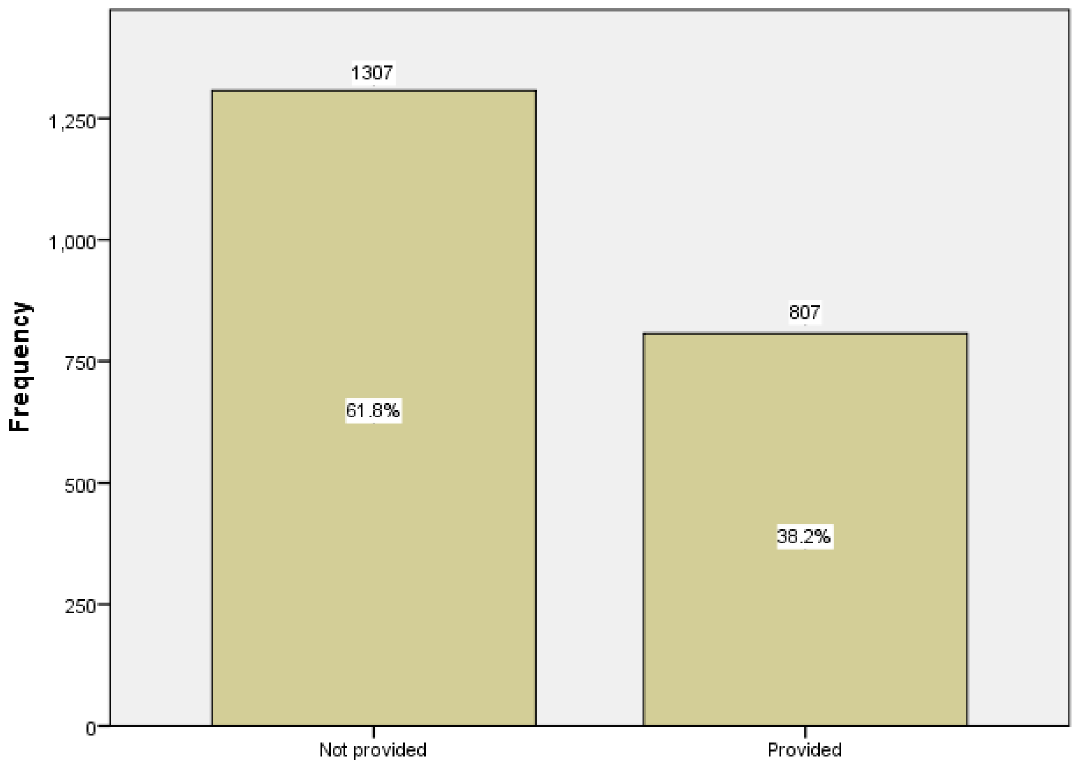


Figure 24: Frequency analysis for fall safety protection system provided

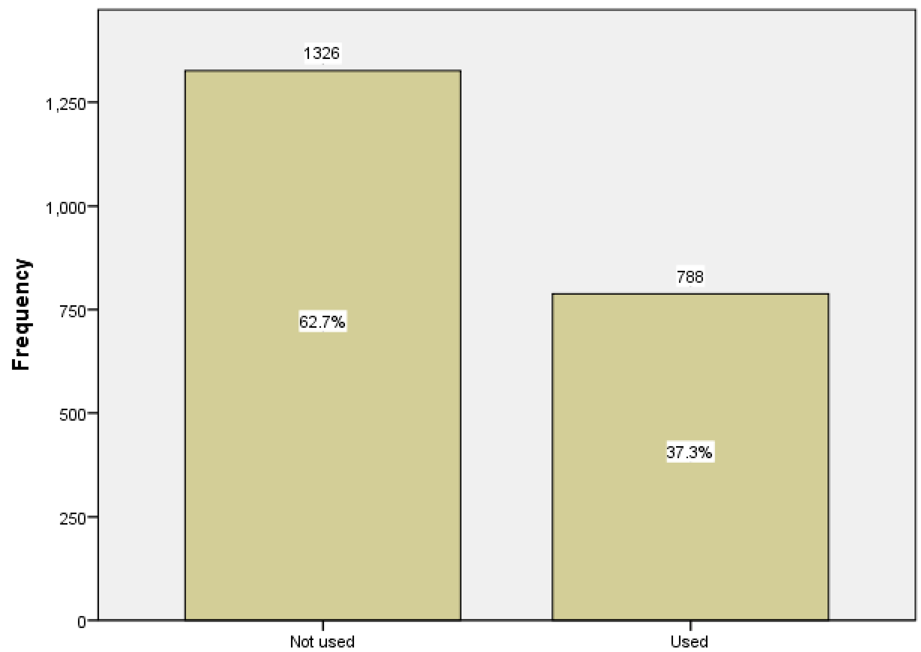


Figure 25: Frequency analysis for fall safety protection system used

As previously explained in Chapter Three, fall safety protection system provided and fall safety protection system used were created as new variables by reviewing all the data to see if the cases have certain citation that indicates the lack of fall safety protection system provisions and lack of usage. Frequencies established are given in Figure 24 and Figure 25. The graphs indicate that 61.8% of the cases did not have fall safety protection system provisions and 62.7% of the victims had not used the system that was provided. We found that only very small fraction of the victims (.9%) had not used the system even when the system was provided. These ties in with the earlier comment regarding fatality cause eminating from the victim as the initiator of the situation.

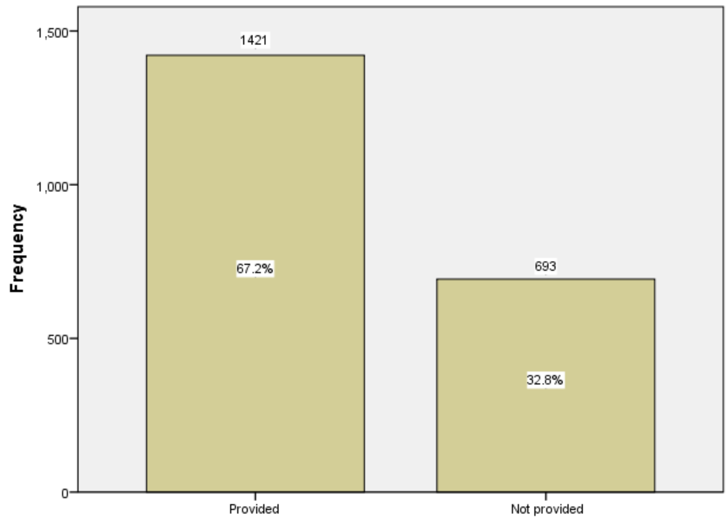


Figure 26: Frequency analysis for fall safety training provided

Another new variable was related to whether safety training was provided to the victim. As seen in Figure 26, in 1421 cases the victim had recieved safety training or/and retraining, versus 693 cases where the victim had no safety training. This observation raises questions on the effectiveness of safety training for the cases examined to prevent the fall accident.

4.2. UNIVARIATE FREQUENCY ANAYSIS OF ROOFERS (1761)

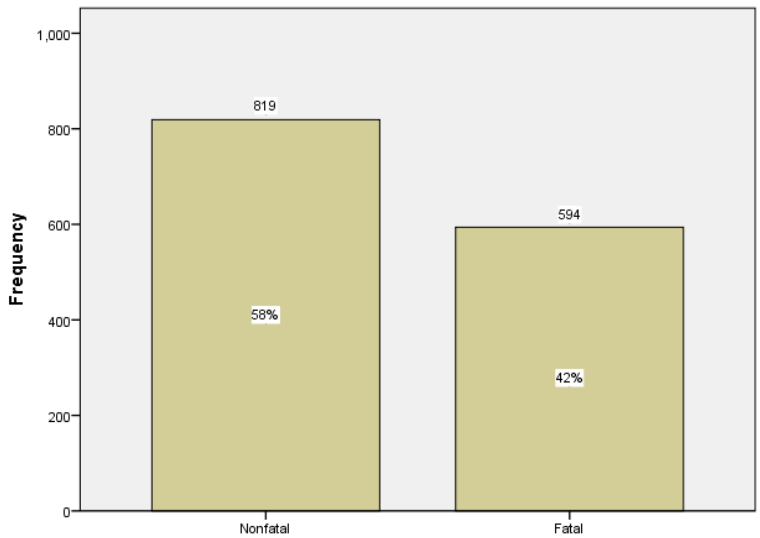


Figure 27: Frequency analysis for degree of injury among roofers

In reference to Figure 27, one can observe that a majority of the accidents among roofers resulted in no fatality (58%).

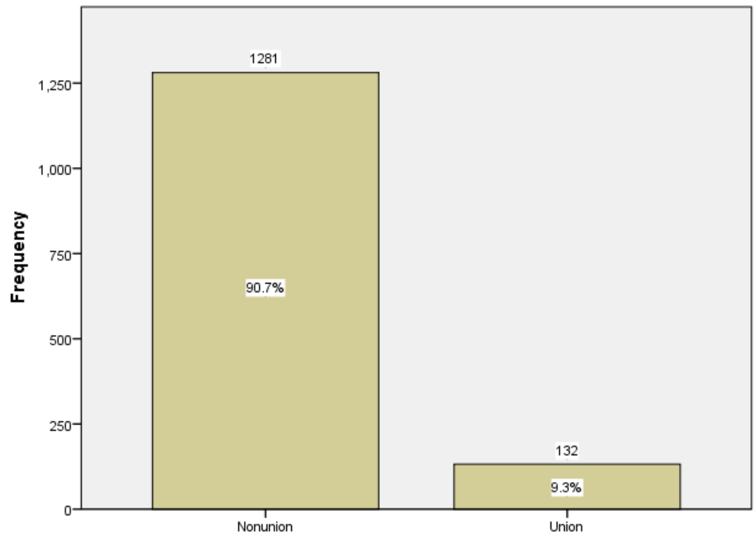


Figure 28: Frequency analysis for union status among roofers

The frequency analysis shown in Figure 28 indicates that most of the accident victims among roofers were nonunion members (90.7%).

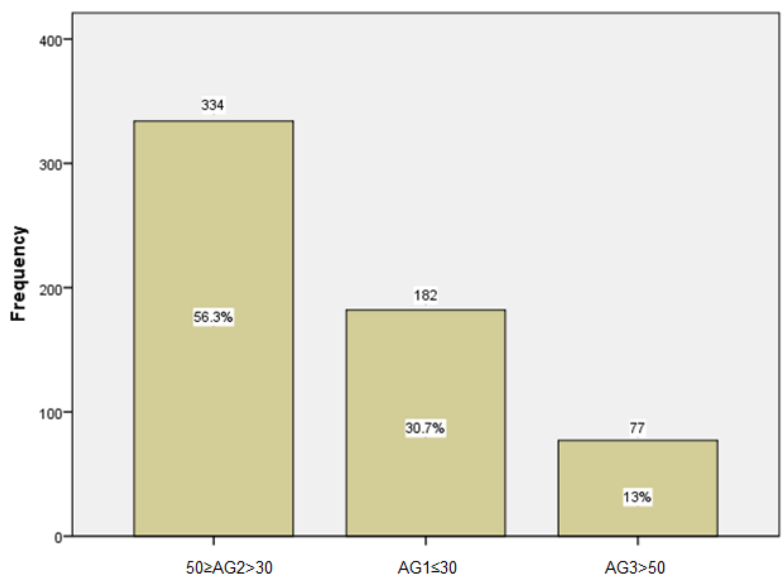


Figure 29: Frequency analysis for age among roofers

Age information was missing in 820 cases. The univariate frequency analysis among the remaining data shows that the age group between 30 and 50 (AG2) is the most accident prone as can be seen in Figure 29.

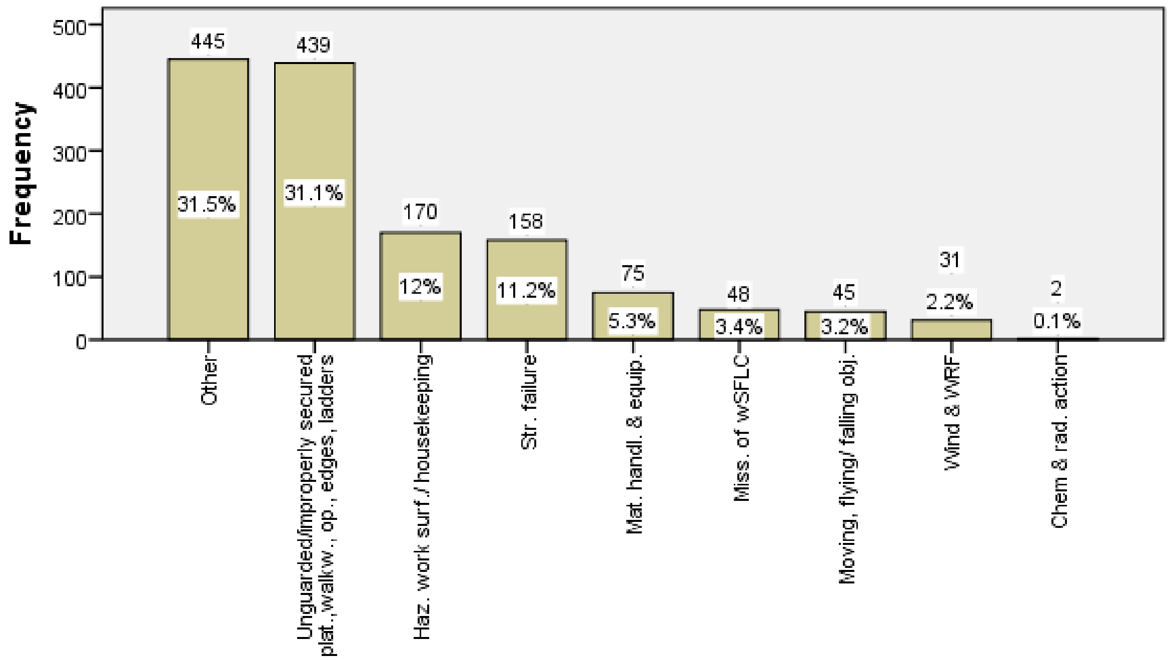


Figure 30: Frequency analysis for environmental factors among roofers

Figure 30 depicts the frequencies of the environmental factors. The “other” category closely followed by the “unguarded improperly secured platform, walkways, openings, edges, ladders” category for roofers. Hazardous work surface/housekeeping, structural failure, material handling and equipment also play roles in accidents.

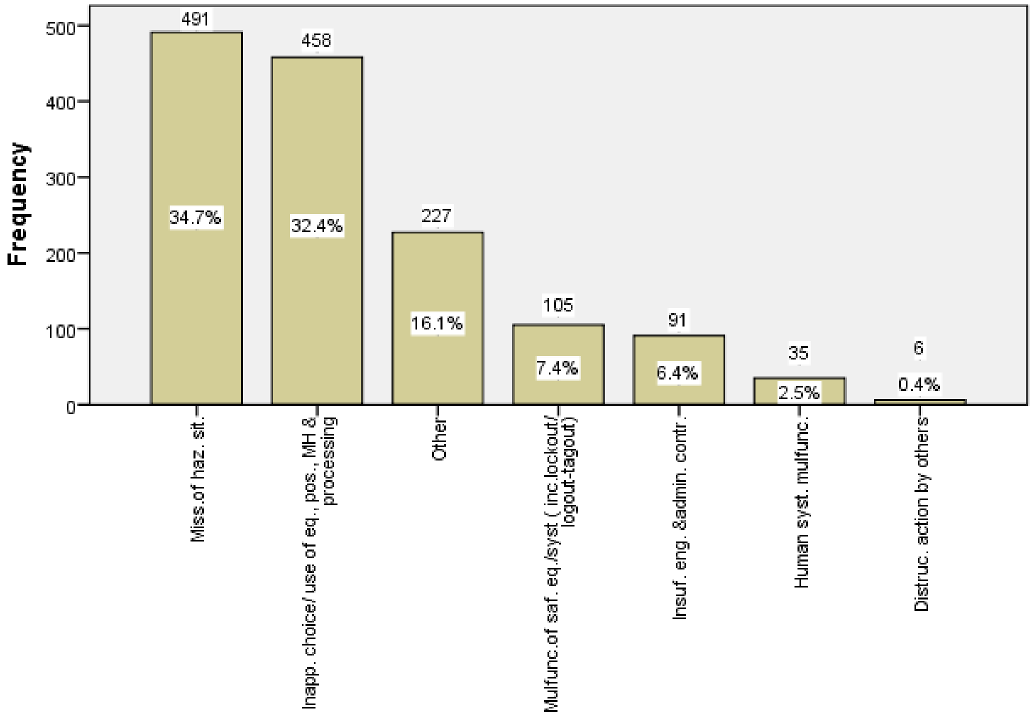


Figure 31: Frequency analysis for human factors among roofers

Figure 31 clearly shows that misjudgment of hazardous situation (34.7%) and inappropriate choice/use of equipment, position, material handling and processing (32.4%) are the highest frequency human factors that cause the accidents for roofers.

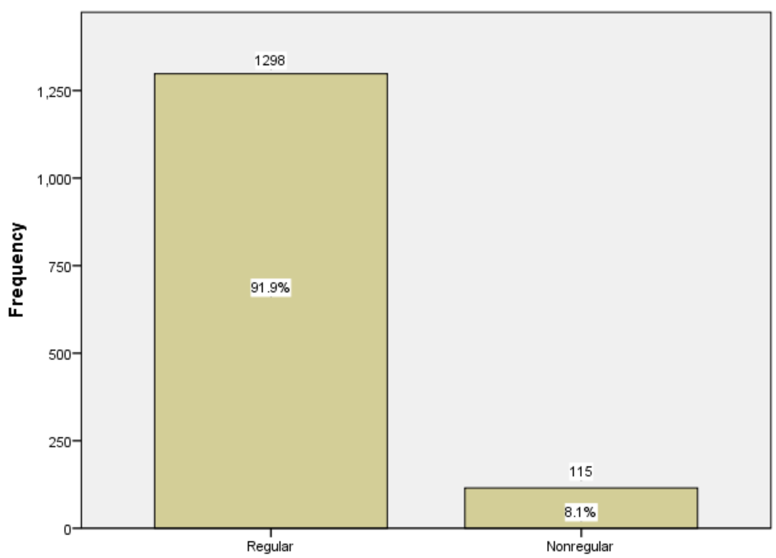


Figure 32: Frequency analysis for task assignment among roofers

Figure 32 shows that a majority of the fall from elevation accidents among roofers occurred while the victim was working on a regularly assigned task.

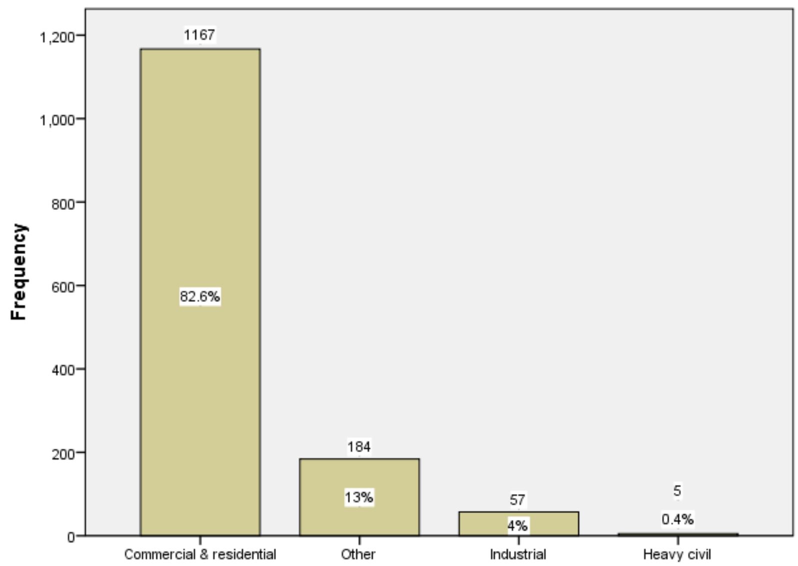


Figure 33: Frequency analysis for construction end use among roofers

Figure 33 displays the construction end use frequencies among the roofers (SIC 1761). It can be observed that commercial and residential end use had the highest accident frequency. As explained earlier, OSHA was accepting properly utilized fall restrain system in lieu of a personal fall arrest system prior to new directive of conventional fall protection which is under 29 Code of Federal Regulations 1926.501(b)(13) which was effective since December 16, 2010. According to BLS data, (http://www.hugsafety.com/2010/12/28/oshas-new-residential-roof-safety-directiv/) falls from roofs were causing forty deaths among roofers each year which was clearly showing the appropriateness of current change of OSHA enforcement on the issue.

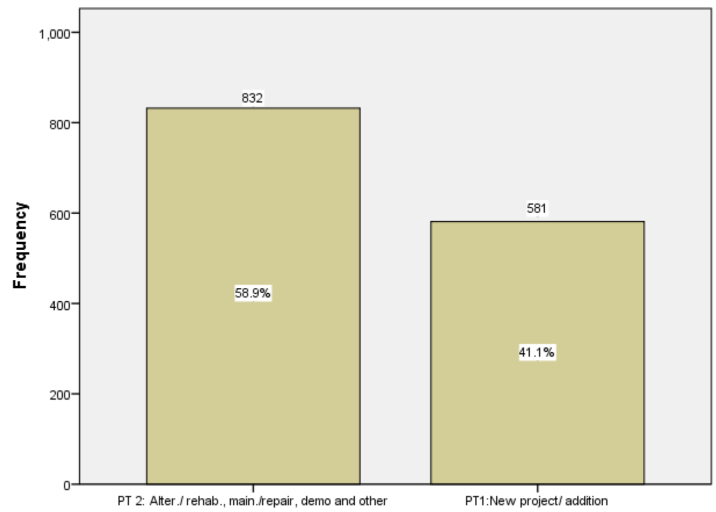


Figure 34: Frequency analysis for project type among roofers

Figure 34 shows that a majority of the accidents occurred in PT2 category which is alterations/rehabilitations, maintenance/repair, demolition and other (58.9%). The roofing industry, which is mostly dominated by small companies which perform repairs and maintenance, especially in residential construction. Fredericks et. al. (2005) also found that roofers who work in small companies (less than 11 employees) were at a higher risk of falling from the roof.

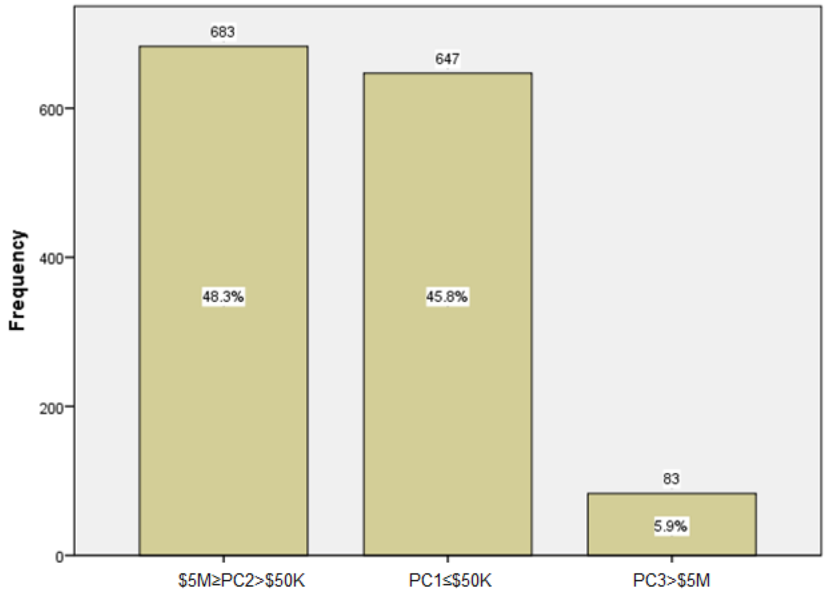


Figure 35: Frequency analysis for project cost among roofers

As seen in Figure 35 most of the accidents occurred in projects costing between $50,000 and $5 million, but the projects that cost less than $50,000 had almost equal frequencies. A paper prepared by Construction Industry Research and Policy Center, University of Tennessee, Knoxville (2011), that was focused on randomly selected 154 fatal accidents occurring between 2005 and 2007, states that 32% of the fatal construction incidents took place in projects costing less than $50,000. Residential roofers mostly work on companies that employ less than 10 employees. (Sa, et. al., 2009). According to BLS 2007, 20% of the roofers are self-employed and they might have improper or no training on fall safety. All these factors affect roofer safety negatively.

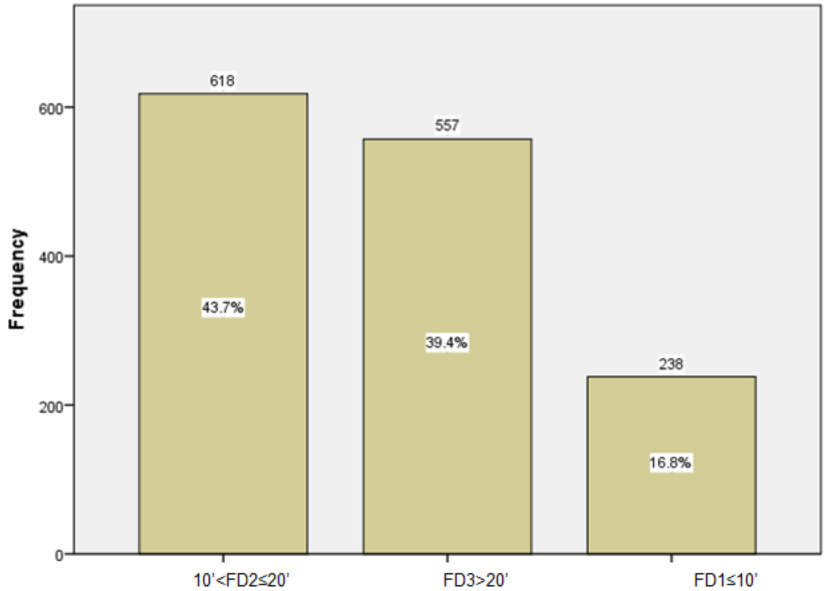


Figure 36: Frequency analysis for fall distance among roofers

Fall distance frequency analysis results are graphed in Figure 36. According to these results most accidents occurred for fall distances between 10 and 20 feet (FD 2) followed by fall distances more than 20 feet (FD 3). Analysis done by Chia et. al., (2005) identified that falls from roofs were more likely to be happening at lower than 20 feet. The roofers were most likely working on 2-story buildings in residential and light commercial construction.

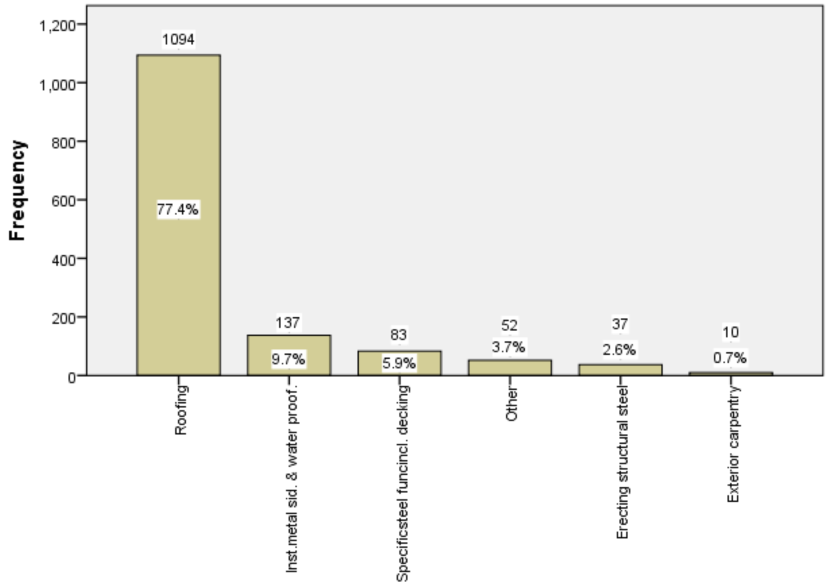


Figure 37: Frequency analysis for construction operation prompting fall among roofers

Figure 37 shows frequencies for the various construction operations prompting fall accidents. Here roofing stands out as the dominating construction operation (77.4%) that leads to an accident.

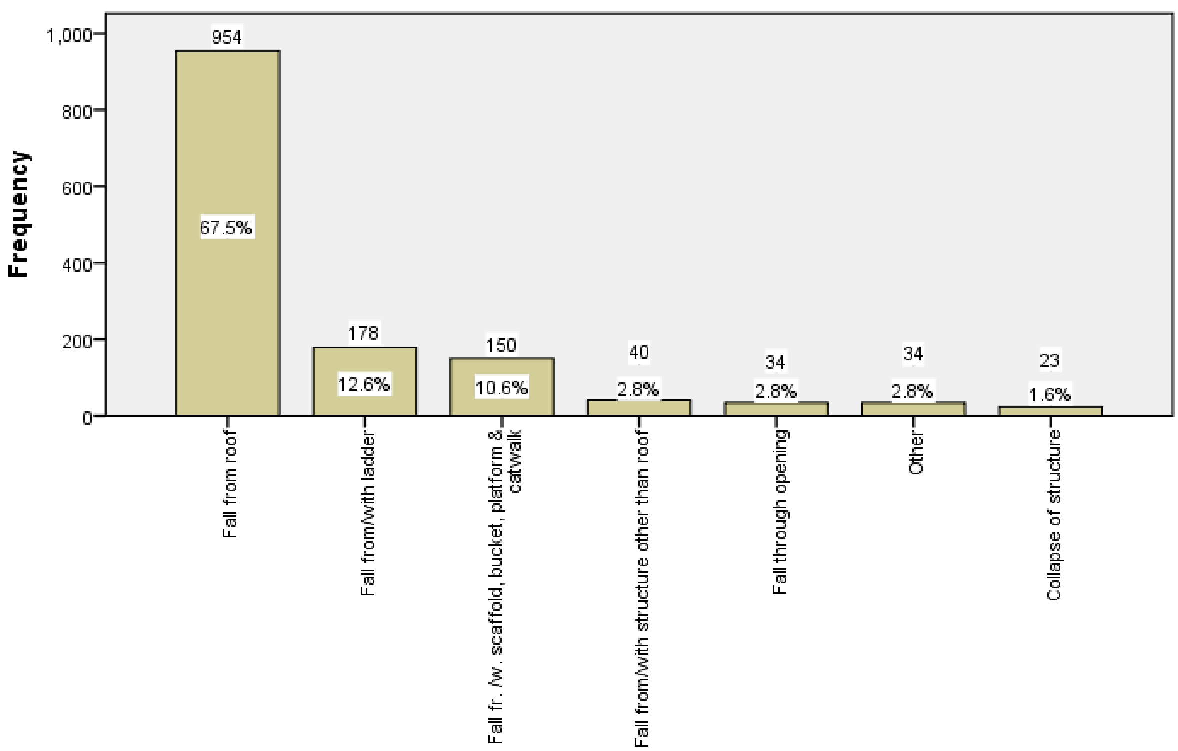


Figure 38: Frequency analysis for fatality/injury cause among roofers

Frequency values for fatality/injury cause are shown as bar graphs in Figure 38. Fall from roof appears to be the most frequently occurring fatality/injury cause at a level of 67.5%. Falls from/with ladder, falls from/with scaffolding, bucket, platform and catwalk also show relatively high frequencies, but significantly below falls from roofs.

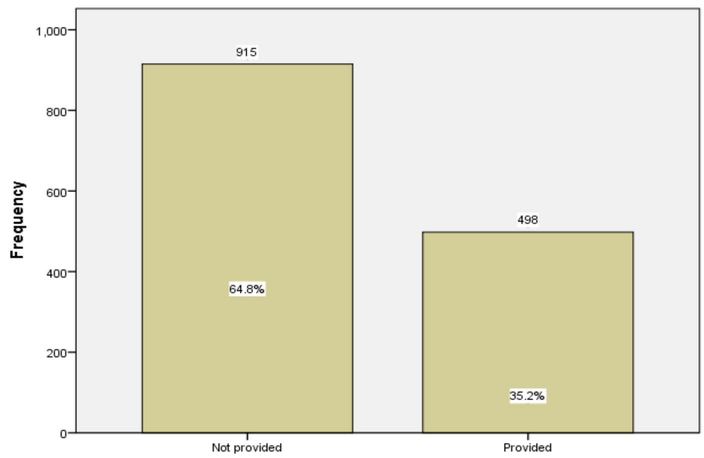


Figure 39: Frequency analysis for fall safety protection system provided among roofers

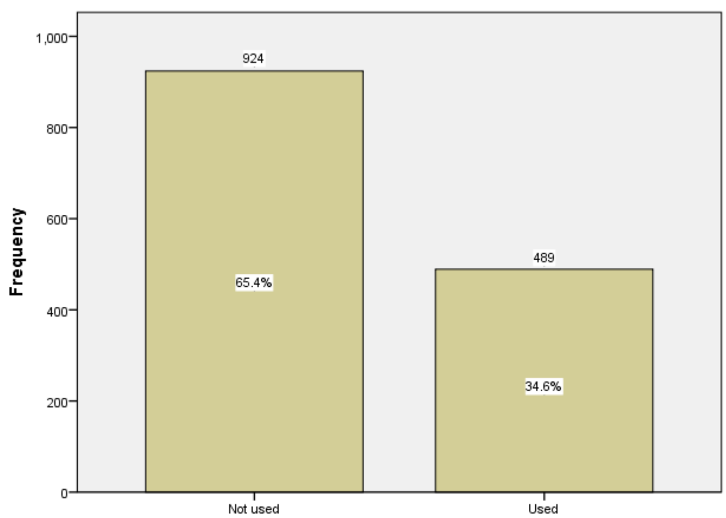


Figure 40: Frequency analysis for fall safety protection system used among roofers

Fall safety protection system (fall restraint system which prevents falling and fall arrest system which protects after one falls from higher level by stopping the fall before one hits the surface below) was provided and used as shown in Figures 39 and 40. These figures indicate that majority of the cases occurred because fall safety system was not provided or it was provided by the company but was not used by the victim. Janicak (1998) mentioned in his study that 45% of the accidents occurred when there was a fall protection system in place, but the victim of the accident was not using it.

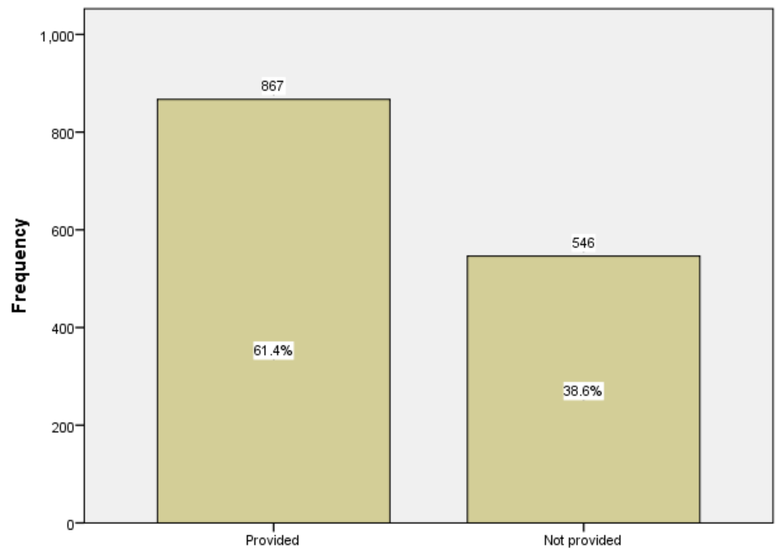


Figure 41: Frequency analysis for fall safety training provided among roofers

Figure 41 shows that fall safety training and retraining provisions were in place in majority of the accidents. This indicates that training provision and effectiveness should be evaluated.

4.3. UNIVARIATE FREQUENCY ANAYSIS OF STEEL WORKERS (1791)

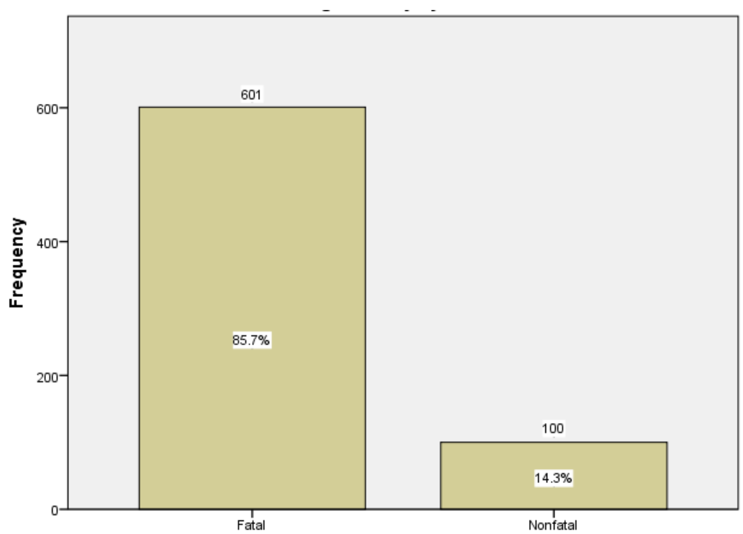


Figure 42: Frequency analysis for degree of injury among steel workers

As seen in Figure 42, the majority of the accidents resulted in fatality (85.7%) for steel workers.

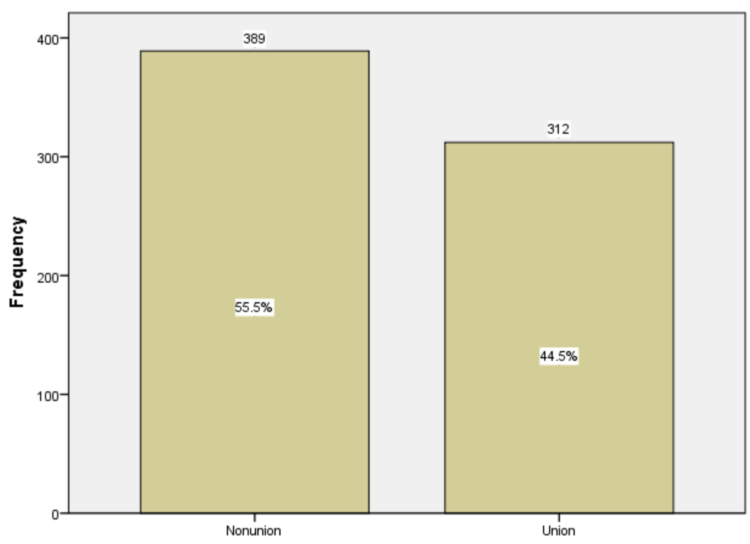


Figure 43: Frequency analysis for union status among steel workers

Figure 43 indicates that most of the victims were nonunion. In comparison to roofers which were 90.7% nonunion, steel workers were more unionized.

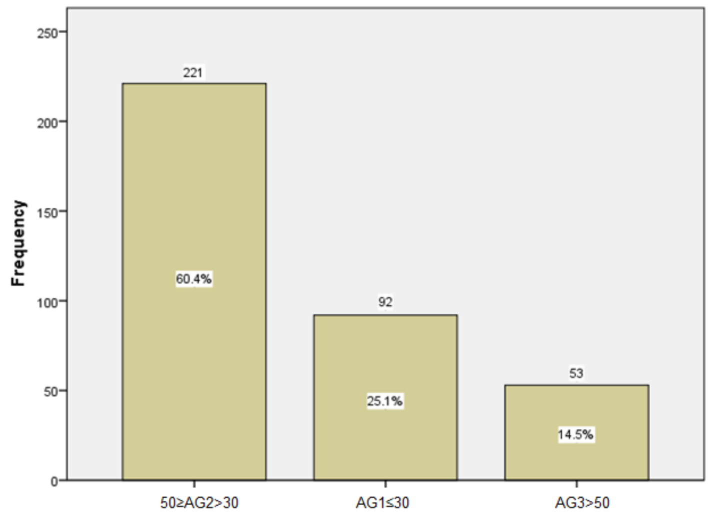


Figure 44: Frequency analysis for age among steel workers

Age information was missing in 335 cases which represent 48% of the steel worker cases. The univariate analysis performed on the remaining data shows that age group 2 (50≥ **AG 2** >30) is the most accident prone age group as can be seen from Figure 44. As shown in Figure 29, the age group 2 is also the most accident prone group for roofers.

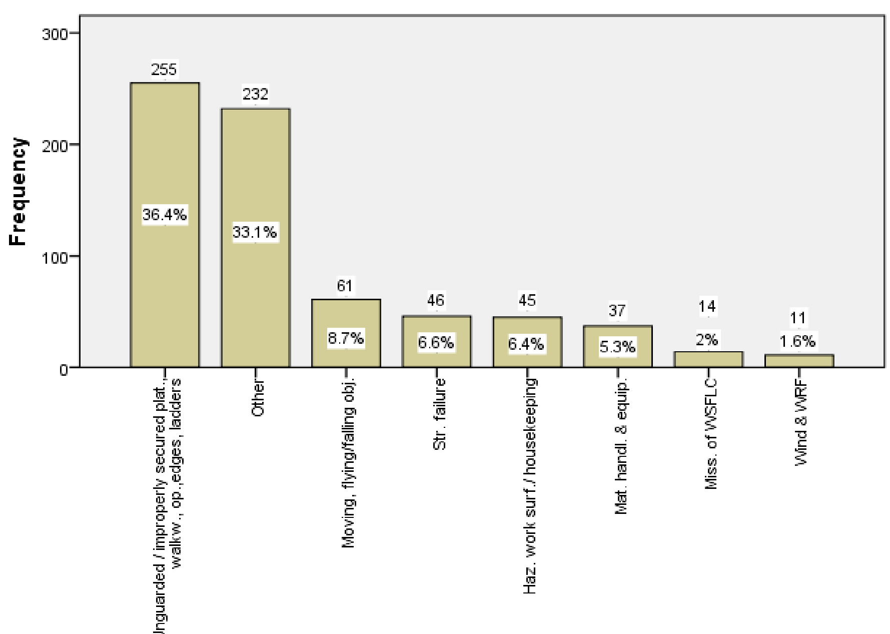


Figure 45: Frequency analysis for environmental factors among steel workers

Figure 45 displays that unguarded/improperly secured platforms, walkways, openings, edges and ladders has occurred most frequently (36.4%). This category very closely followed by the “other” (33.1%). Remaining categories showed less than ten percent frequency distribution.

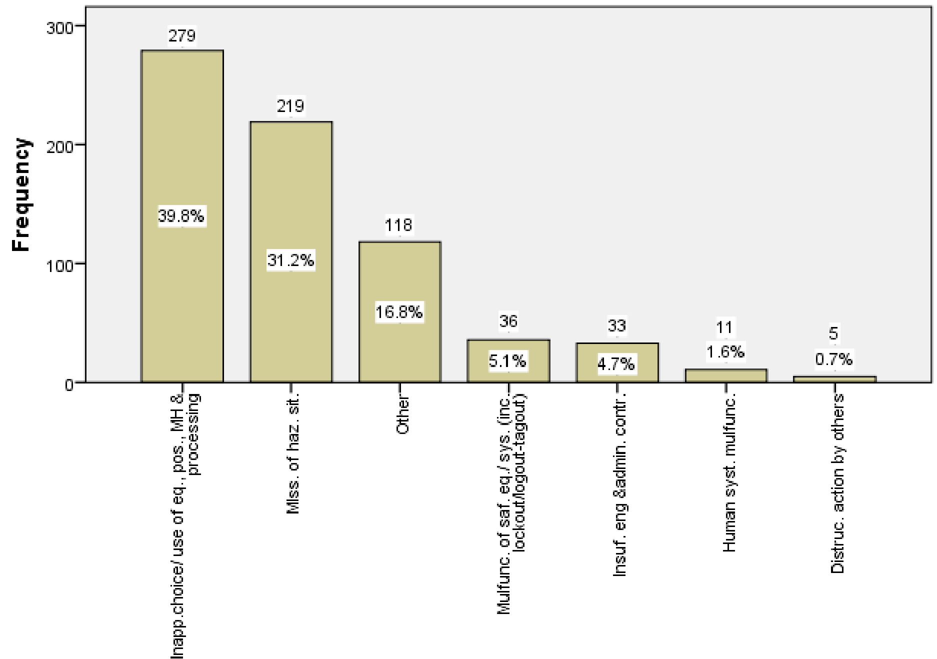


Figure 46: Frequency analysis for human factors among steel workers

So far as human factors considered, inappropriate choice/use of equipment position, material handling and processing is the most frequently occurring human factors for steel worker accidents, closely followed by misjudgment of hazardous situation. These are laid out in Figure 46.

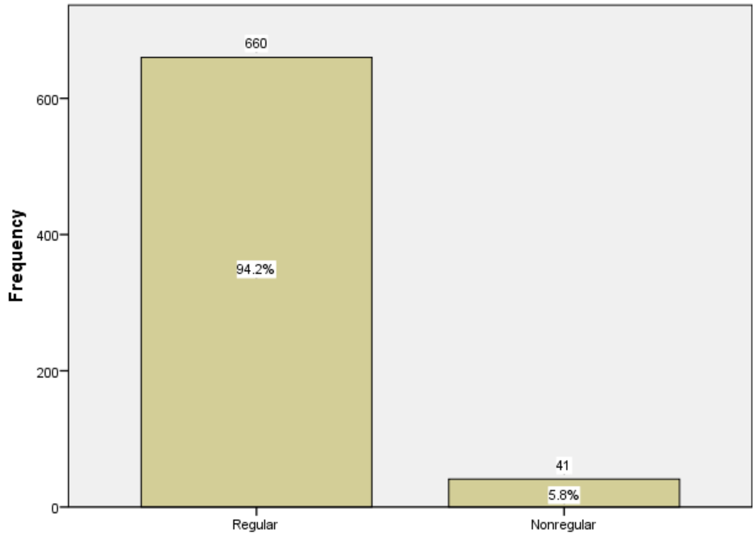


Figure 47: Frequency analysis for task assignment among steel workers

Figure 47 shows that for steel workers a majority of the falls from elevation occurred while the victim was working on a regularly assigned task. This is consistent with the results obtained for roofers.

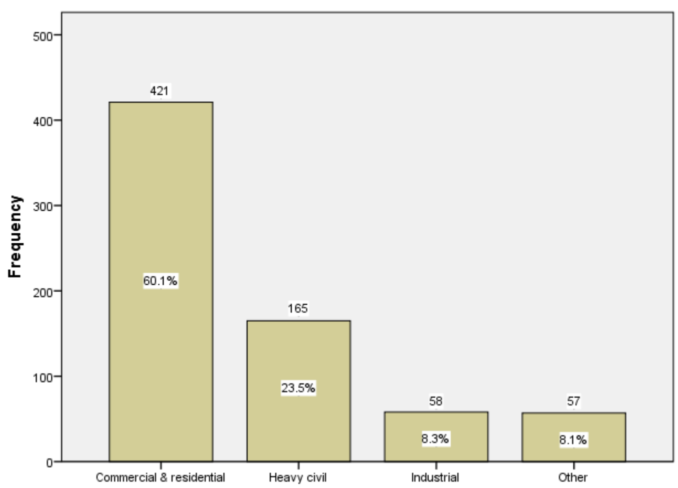


Figure 48: Frequency analysis for construction end use among steel workers

Construction end use frequencies are graphed in Figure 48, where it is observed that commercial and residential work had the highest accident frequency among steel workers.

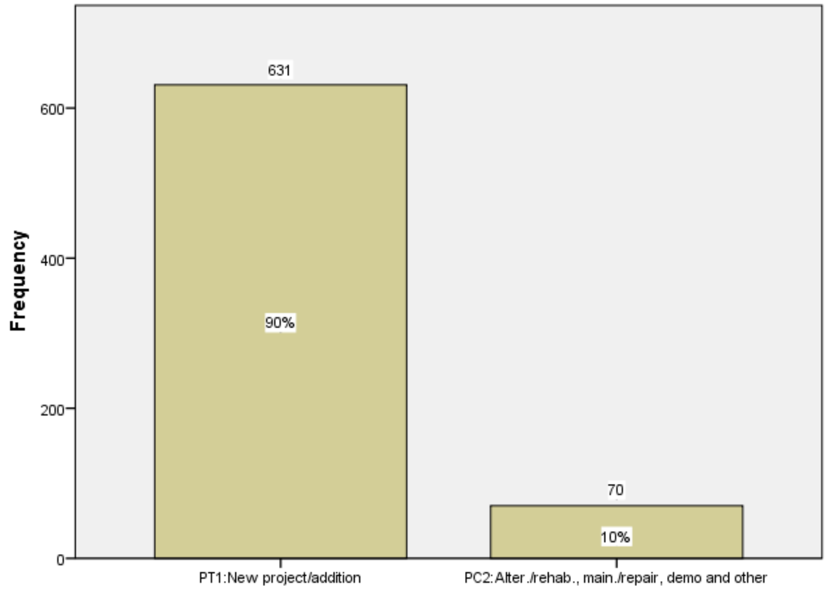


Figure 49: Frequency analysis for project type among steel workers

As seen in Figure 49, most accidents occurred in project type 1, which is new project or addition. On the other hand, roofer accidents occurred mostly in project type 2 which is alterations/rehabilitations, maintenance/ repair, demolition and other.

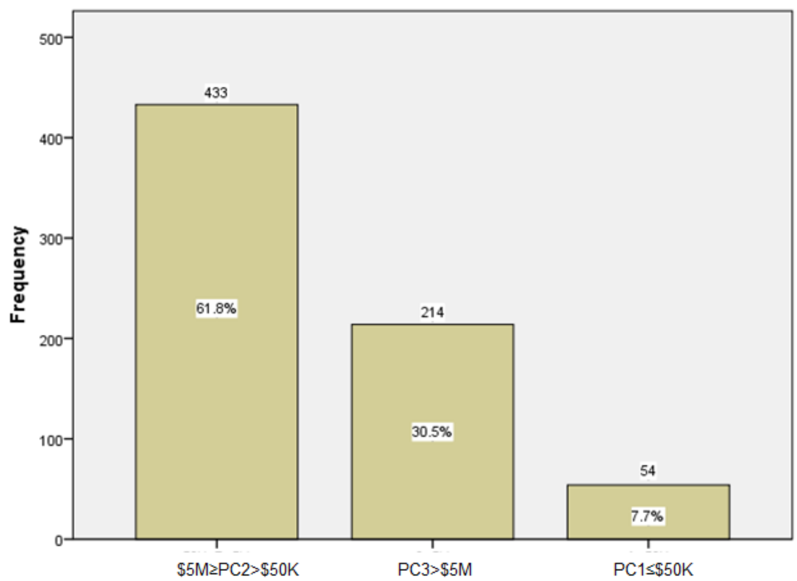


Figure 50: Frequency analysis for project cost among steel workers

Even though the project cost less than $5 million and more than $50,000 was the highest cost group for both trades, steel workers also had 30.5% of the accidents occurring in projects costing over $5 million. It can be explained that steel worker accidents mostly occur in large size and high rise construction projects. (Figure 50)

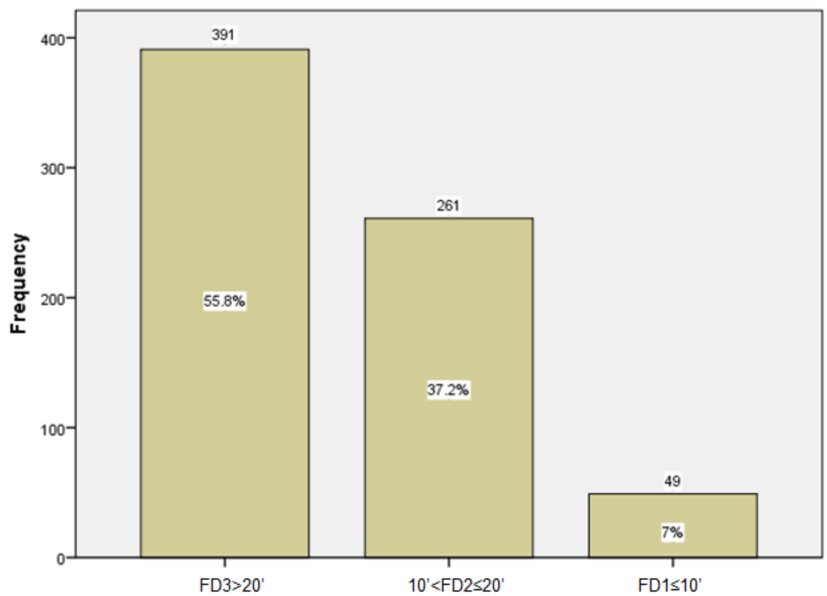


Figure 51: Frequency analysis for fall distance among steel workers

Steel workers mostly work on higher elevations compared to roofers; therefore, as shown in Figure 51, over 20 feet was the most frequent height for fall accidents occuring among steel workers. Referring back to Figure 36, heights of between 10 feet to 20 feet were the most critical for roofers.

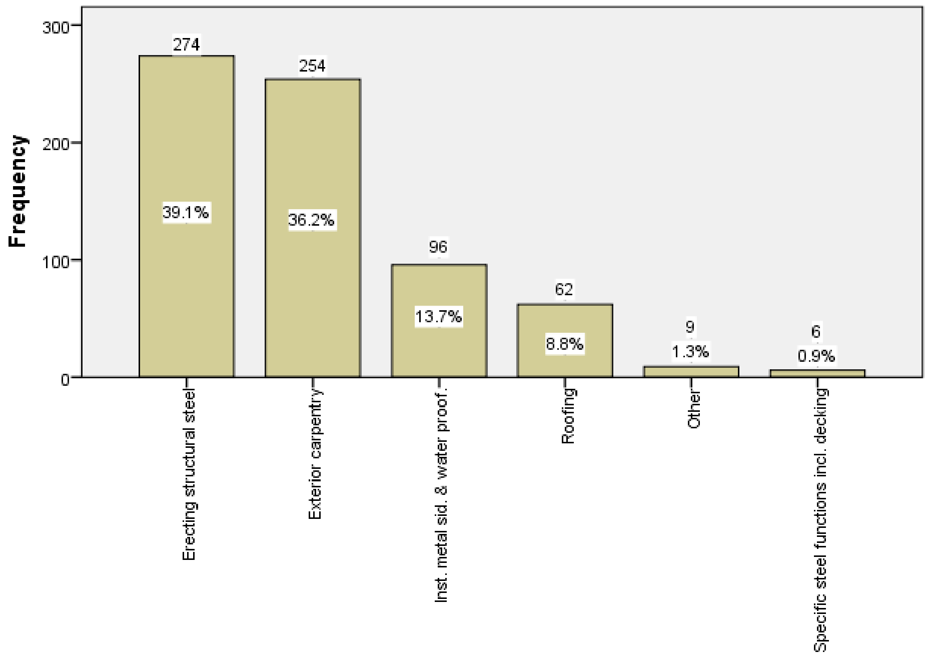


Figure 52: Frequency analysis for construction operation prompting fall among steel workers

Figure 52 exibits frequencies for the various construction operations prompting fall accidents among steel workers. Steel erection stands out as the dominating construction operation (39.1%) that leads to an accident closely followed by exterior carpentry (36.2%) . Others with relatively significant percentages are installing metal siding and water proofing and roofing.

Frequency values for fatality/injury cause are bar graphed in Figure 53, where fall from/with structure other than roof comes out as the most frequently occurring fatality/injury cause (42.7%). Others with relatively significant percentages are fall from roof, other, fall from/with ladder and fall from/with scaffold, bucket, platform and catwalk.

As shown in Figure 54 fall safety protection system, was not provided for 55.9 % of the victims.

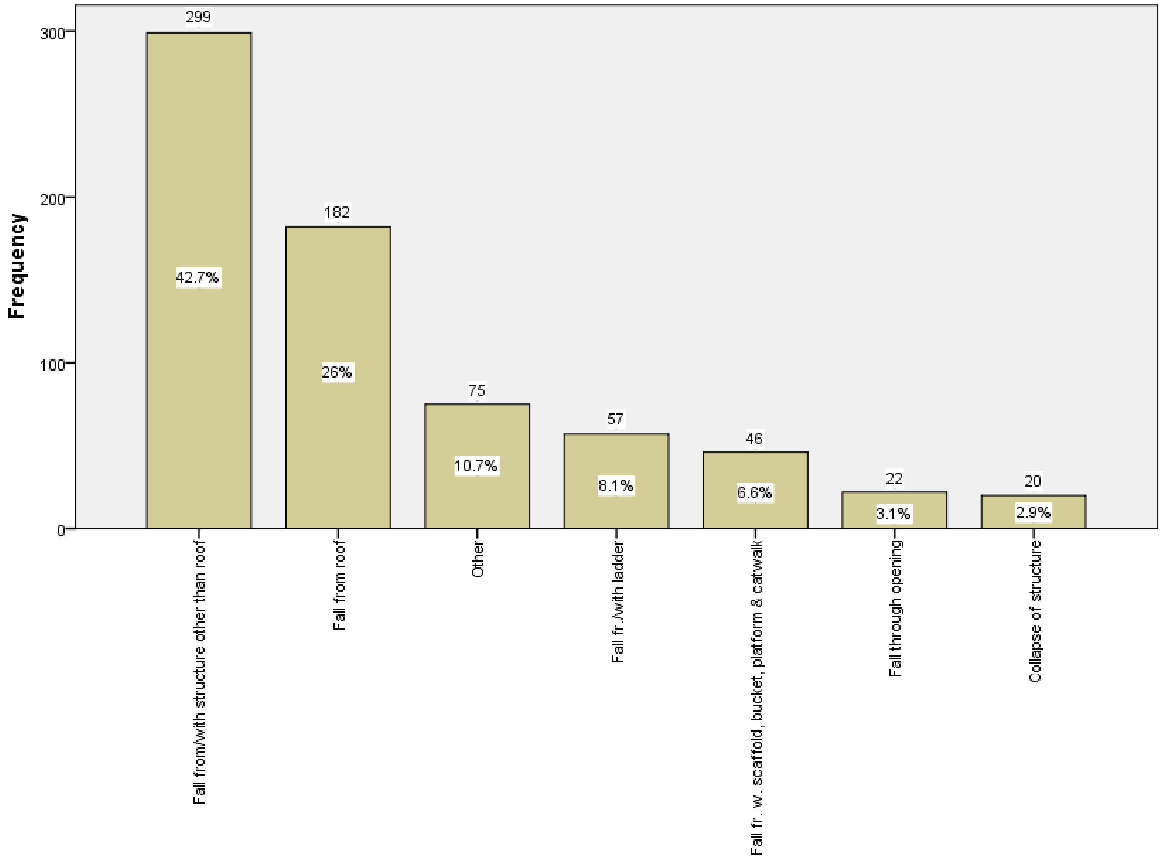


Figure 53: Frequency analysis for fatality/injury cause among steel workers

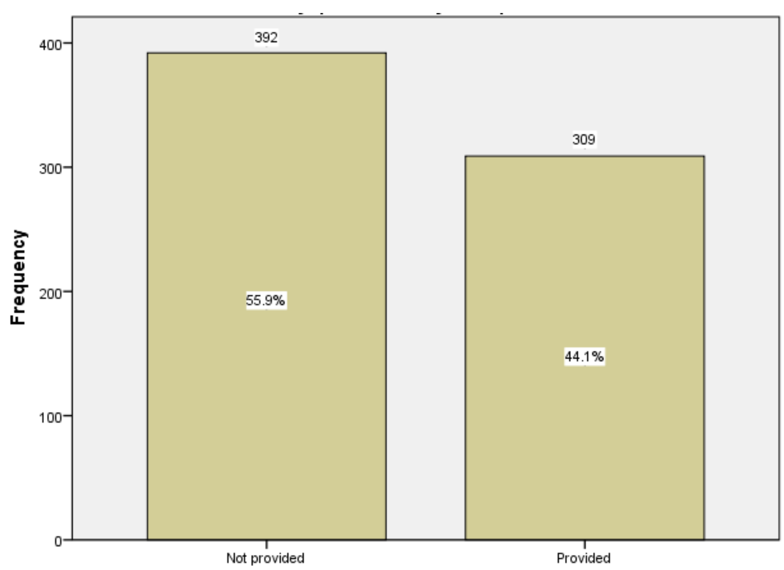


Figure 54: Frequency analysis for fall safety protection system provided among steel workers

OSHA Part 26, Steel Erection, rule 2645(1) requires that “fall protection for employees engaged in steel erection activity, when they are exposed to a fall of more than 15 feet above a lower level”. Fall protection includes guardrail systems, safety net systems, personal fall arrest systems, positioning device systems, or fall restraint systems. Also, connectors and workers who are working at the controlled decking zones are under OSHA Part 26 rule 2646. It states that “person who is doing the connection job working at the heights more than 30 feet must be provided and use fall protection. At heights more than 15 feet and up to 30 feet connectors must wear fall protection equipment with the ability to be tied off, unless guardrail systems or safety net systems are in place”. (http://www.michigan.gov/documents /cis_wsh_constfact_steel_ erection _ 163281_7.htm)

According the citations issued for the 701 cases, 55.9% of the cases did not have fall safety protection system, or it was not in good working condition, which resulted in accidents when combined with the other contributing factors. Also, Janicak (1998) recommended in his research that companies should give adequate training to the workers on how to properly install, use, test, and inspect fall protection systems in order to prevent falls properly.

As shown in Figure 55, 57.3% of the steel workers did not use a fall safety protection system. We noted that only a very small number of the victims (10 cases) had not used the system even when the system was provided.

As seen in Figure 56, 79% of the cases the victim had safety training versus in 21% of the cases the victim had no safety training. This observation raises questions on the effectiveness of safety training to prevent fall accidents among steel workers.

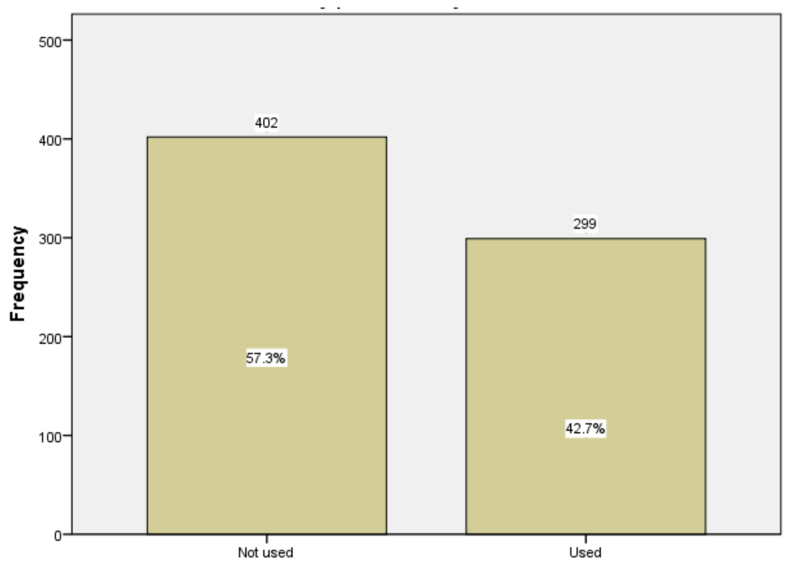


Figure 55: Frequency analysis for fall safety protection system used among steel workers

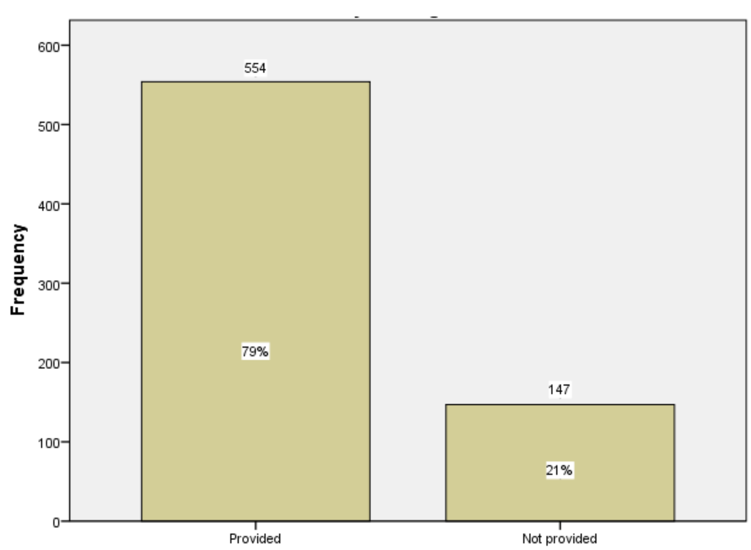


Figure 56: Frequency analysis for fall safety training provided among steel workers

4.4. SUMMARY OF FINDINGS

4.4.1. WHOLE DATA

- Residential and commercial construction was the highest frequency construction end use (75.1%).
- Age group 2(50≥AG2>30) is the most accident prone group.
- New project or new addition constitutes a majority (57.3%) of the accidents.
- Project cost group 2 ($50K<PC2≤ $5M) is most accident susceptible.
- Most fall accidents occurred over heights exceeding 20 feet (44.8%). Average fall distance was 23.77 feet.
- Roofing operation is the most frequently occurring construction activity prompting fall accidents (54.7%).
- Fall safety protection system was not provided in 61.8% of the cases and not used in 62.7% cases.
- Fall safety training was provided in 67.2% of the cases.
- A majority of the fall accidents (%79) occurred among nonunion workers.
- Unguarded/improperly secured platforms, walkways, openings, edges and ladders were the highest frequency environmental factor associated with falls (32.8%).
- A great majority of the accidents (92.6%) occurred while the victim was working on a regularly assigned task.

- For the human factors, inappropriate choice/use of equipment, position, material handling, and processing (34.9%) showed the highest frequencies, closely followed by misjudgment of hazardous situation (33.6%).
- Most accidents occurred for roofers (66.8%).

4.4.2. ROOFERS

- Nonfatal falls accounted for 58% of the roofer accidents.
- The age group between 30 to 50 (Age group 2) is the most accident prone (56.3%).
- The "other" category which includes pinch point action, catch point /puncture action, squeeze point action, temperature +/- tolerance level, illumination, and overpressure/under pressure, (31.5%) has occurred most frequently, closely followed by the unguarded improperly secured platform, walkways, openings, edges, ladders (31.1%) as the environmental factor.
- Fall from roof appears most frequently as the event leading to fatality/injury at a level of 67.5%.
- A majority of the falls among roofers happened while the victim was working on a regularly assigned task. (91.9%) Commercial and residential end use had the highest accident frequency (82.6%).
- Most of the accidents occurred in Project type 2 which is alterations/rehabilitation, maintenance/repair, demolition and other (58.9%) and in projects costing between $50,000 and $5 million,(48.3%), while the projects that cost less than $50,000 (45.8%) had almost equal frequencies.

- Fall distances between 10 and 20 feet (group 2) (43.7%) followed by fall distances more than 20 feet (group 3) (39.4%) were the most accident prone groups.
- Roofing stands out as the dominating construction operation (77.4%) that leads to a fall accident.
- Majority of the cases occurred because fall safety system was not provided. In .6% of the cases, even when it was provided by the company, it was not used by the victim.
- Fall safety training provisions were in place in majority of the accidents (61.4%). This indicates that training effectiveness should be evaluated.

4.4.3. STEEL WORKERS

- The majority of the accidents resulted in fatality (85.7%) for steel workers.
- Most of the victims were nonunion (55.5%); in comparison to roofers which were 90.7% nonunion. However a larger percentage of steel workers (44.5%) were unionized.
- Age group 2 ($50 \geq 2 > 30$) is the most accident prone age (60.4%).
- Unguarded/improperly secured platforms, walkways, openings, edges and ladders is the most frequently occurring environmental factor (36.4%).
- Inappropriate choice/use of equipment position, material handling and processing (39.8%) is the most frequently occurring human factor for steel

worker accidents, closely followed by misjudgment of hazardous situation (31.2%).

- A majority of the fall from elevation accidents (94.2%)occurred while the steel worker was working on regularly assigned task.
- Most steel worker falls, (90%) as opposed to roofer falls (41.1%), occurred in new projects or additions.
- Even though projects costing less than $5 million and more than $50,000 was the most accident occurring cost group for both trades, steel workers had 30.5% of the accidents occurring in the over $5 million projects compare to 48.3% of the accidents occurring in the less than $50,000 projects in roofers.
- Fall from/with structure other than roof came out as the most frequently occurring fatality/injury cause (42.7%).
- Fall safety protection system was not provided for 55.9 % of the steel workers.
- A majority of steel workers (57.3%) did not use a fall safety protection system.
- In a majority of the cases (79%) the victim had safety training while in 21% of the cases the victim had no safety training. This observation raises questions on the effectiveness of safety training to prevent fall accidents among steel workers.
- Fall distance over 20 feet (group #3) was the most accident prone group (55.8%).

4.5. CROSS TABULATION ANALYSIS OF WHOLE DATA

Cross tabulation analysis was performed on the variables previously listed in Table 7. First, the seven dichotomous independent variables were analyzed, taking the degree of injury as the dependent variable. The results are given in Table 8. As shown in this table, p values for chi square hypothesis testing are below 0.05 for union status, SIC code, project type, fall safety system provided, and fall safety system used, indicating that they are significant. Phi values (also given in Table 7) indicate the strength of the relationship between the degree of injury and the variables that are found to be significant. Also note that there are negative weak relationships; however, the negative sign can be ignored in interpreting these results. (http://www.people.vcu.edu /~pdattalo /702SuppRead/MeasAssoc/NominalAssoc.html).

According to the convention adopted in this research, all but one of the relationships is weak. The relationship between the degree of injury and SIC code has moderate strength. The odds ratio values given in Table 7 are discussed below with respect to each of the variables in Tables 8 through 14.

Table 7: Cross tabs with degree of injury vs. independent dichotomous variables

Independent variable	Chi Square Value	Df.	Significance (p)	Phi or Cramer's V	Odds ratio
Union status	76.151	1	.000	.190	2.77
SIC code (1791 vs. 1761)	364.061	1	.000	.415	8.52
Task assignment	1.721	1	.190	-	-
Project type	25.461	1	.000	-.110	1.56
Fall safety protection system provided	4.382	1	.036	-.046	1.22
Fall safety protection system used	6.659	1	.010	-.056	1.27
Safety training provided	.920	1	.338	-	-

It is observed from Table 8 that among 2114 cases, nonunion worker fatalities are 72.2 % compared to union fatalities of 27.8%. The chi square significance is less than 0.05; hence there is a significant relationship between the degree of injury and union status and based on phi, this relationship is a weak one. The odds ratio value given in Table 7 indicate that if a worker was unionized the odds of fatality is 2.77 times higher than if a worker is nonunionized.

Table 8: Degree of injury vs. union status

Union status	Nonfatal	Fatal	**Total**
1.Union	112 (12.2%)	332 (27.8%)	444
0.Nonunion	807 (87.8%)	863 (72.2%)	1670
Total	919	1195	2114

As observed in Table 9, among the 2114 falls from elevation cases, 1413 (66.8%) are roofers and 701 (33.2%) are steel workers. For the roofers, 42% of the cases have resulted in a fatality and 58% are nonfatal. For steel workers, 85.7% of the cases turned out fatal, and 14.3% turned out nonfatal. Although only 1/3 (33.2%) of the total fall accidents involved steel workers, most of these resulted in fatalities (85.7%) in comparison to 42% of roofer accidents ending up fatal. The phi value in Table 7 shows a moderate significant relationship between the degree of injury and SIC code. Further, the odds ratio shown in Table 7 reveals that being a steel worker increases the odds of fatality 8.52 times compared to roofers.

Table 9: Degree of injury vs. SIC Code

SIC code	Nonfatal	Fatal	**Total**
1761 (roofers)	819 (58%)	594 (42%)	1413
1791 (steel workers)	100 (14.3%)	601 (85.7%)	701
Total	919	1195	2114

Results given in Table 10 show that 92% of the fatal accidents involve the workers who worked on a regularly assigned task. In contrast, 8% of the fatalities occurred in non-regularly assigned tasks. A report, based upon OSHA-inspected fatal events in construction during calendar 2003 was conducted by Construction Industry Research and Policy Center University of Tennessee, Knoxville for Office of Statistics OSHA, U.S. Department of Labor (Construction Industry and research policy center, University of Tennessee, Knoxville, OSHA's Office of statistics, 2003), states that 72.3% of the time the victim was on the regular task site when the accident occurred, which supports this research finding. Fatal and nonfatal accidents happen more frequently on regularly assigned tasks. As seen in Table 7 that the relationship between the degree of injury and the task assignment is not significant.

Table 10: Degree of injury vs. task assignment

Task assignment	Nonfatal	Fatal	**Total**
1.Regular	859 (93.5%)	1099 (92%)	1958
0. Nonregular	60 (6.5%)	96 (8%)	156
Total	919	1195	2114

As seen from the cross tabulation results of Table 11, fatalities mostly occur (62.1%) in project type 1 which is new construction or addition, in comparison to project type 2 which is alteration/rehabilitation, maintenance/repair, demolition and other (37.9%). The odds ratio in Table 7 shows that, working on a new project or addition increases the odds of fatality among steel workers and roofers by 1.56 times.

Table 11: Degree of injury vs. project type

Project type	Nonfatal	Fatal	**Total**
PT1: New project or new addition	470 (51.1%)	742 (62.1%)	1212
PT2: Alteration/rehabilitation, maintenance/repair, demolition and other	449 (48.9%)	453 (37.9)	902
Total	919	1195	2114

As it shown in Table 12, most of the fatal accidents occurred while fall safety protection system was absent (63.8%). Pearson chi square significance is ".036", hence there is a significant relationship between fall safety protection system provision and degree of injury. The phi value of -.046 means there is a weak negative relationship. As shown in Table 7, the odds ratio indicates that when the fall safety protection system is not provided, the odds of fatality is 1.22 times higher compared to safety protection system provided.

Table 12: Degree of injury vs. fall safety protection system provided

Fall safety protection system provided	Nonfatal	Fatal	**Total**
Not provided	545 (59.3%)	762 (63.8%)	1307
Provided	374 (40.7%)	433 (36.2%)	807
Total	919	1195	2114

As shown in Table 13, workers who have not used the safety protective system even when provided account for 65.1% of the fatalities. There is a significant relationship between fall safety system used and the degree of injury and a phi value of -.056 means a weak negative relationship. The odds ratio shown in Table 7 indicates that if a worker is not using safety protection system, the odds of fatality is 1.27 times higher compared to when safety protection system is used.

Table 13: Degree of injury vs. fall safety protection system used

Fall safety protection system used	Nonfatal	Fatal	**Total**
Not used	548 (59.6%)	778 (65.1%)	1326
Used	371 (40.4%)	417 (34.9%)	788
Total	919	1195	2114

It is observed in Table 14 that 66.4% of the fatal cases occurred with fall safety training provided. As seen in Table 7 that there is not a significant relationship between the degree of injury and safety training provision.

Table 14: Degree of injury vs. safety training provided

Safety training provided	Nonfatal	Fatal	Total
Not provided	291 (31.7%)	402 (33.6%)	693
Provided	628 (68.3%)	793 (66.4%)	1421
Total	919	1195	2114

After the seven dichotomous variables were analyzed, the seven multi-valued variables were analyzed. The results are given in Table 15. As shown, the chi square significance values are below 0.05 for construction end use, project cost, fall distance, construction operation prompting fall, fatality/injury cause, environmental factors, and human factors.

Table 15: Cross tabs with degree of injury vs. independent multi- valued variables

Independent variables	**Chi Square Value**	**df**	**Significance (p)**	**Phi or Cramer's V**
Construction end use	76.294	3	.000	.190
Project cost	46.326	2	.000	.148
Fall distance	145.512	2	.000	.262
Construction operation prompting fall	235.820	5	.000	.334
Fatality /injury cause	133.369	6	.000	.251
Environmental Factors	69.524	8	.000	.181
Human factors	21.633	6	.001	.101

As seen in Table 16, there were more than 50% (1155) of the cases which had no age information. It should also be noted that there are no nonfatal accident cases observed among the 959 cases; therefore, the cross tab analysis for age is not included in Table 15.

Among age groups, group 2 (30<**AG2** ≤50) was the highest fatality occurring group, which agrees with the findings of Huang and Hinze (2003).

Table 16: Degree of injury vs. age

Age Group	Nonfatal	Fatal
AG 1 ≤30	0	274 (28.5%)
30<**AG 2** ≤50	0	555 (57.9%)
AG 3>50	0	130 (13.6%)
Total	0	959

Results of the cross tab analysis given in Table 17 show that commercial and residential end use is the most frequently occurring fatal accident group. Also, this end use group has the highest nonfatal accident occurrence. Going back to Table 15, the

Pearson chi square value is ".000", hence there is a significant relationship between the degree of injury and the construction end use. The phi value of .190 means a weak relationship.

Table 17: Degree of injury vs. construction end use

Construction end use	Nonfatal	Fatal	**Total**
1: Commercial & residential	770 (83.8%)	818 (68.5%)	1588
2: Industrial	24 (2.6%)	90 (7.5%)	114
3: Heavy civil	9 (1.0%)	54 (4.5%)	63
4: Other	116 (12.6%)	233 (19.5%)	349
Total	919	1195	2114

According to Table 18, 53.9 % of the fatal accidents occur with the project cost group of **2** ($50K< PC 2≤ $5M). As it indicated in Table 15, Pearson chi square is ".000", hence there is a significant relationship between the project cost and the degree of injury, and a phi value of .148 means a weak relationship.

Table 18: Degree of injury vs. project cost

Project cost	Nonfatal	Fatal	**Total**
PC 1 ≤$50K	362 (39.4%)	339 (28.4%)	701
$50K<**PC 2**≤$5M	472 (51.4%)	644 (53.9%)	1116
PC 3>$5M	85 (9.2%)	212 (17.7%)	297
Total	919	1195	2114

As seen in Table 19, the fall distance of 20 feet and higher is the most fatality prone height (55.8%). Table 15 shows that Pearson chi square is ".000", hence there is a significant relationship between the fall distance and the degree of injury. A phi value of .262 means there is a weak relationship.

Table 19: Degree of injury vs. fall distance

Fall distance	Nonfatal	Fatal	**Total**
FD 1 ≤10’	182 (19.8%)	105 (8.8%)	287
10 <**FD 2** ≤ 20’	456 (49.6%)	423 (35.4%)	879
FD 3 >20’	281 (30.6%)	667 (55.8%)	948
Total	919	1195	2114

Table 20 shows that roofing is the highest fatality prone construction operation prompting a fall (43.7%), followed by structural steel erection (19.9%). Again, Table 15 indicates that Pearson chi square is “.000”, so there is a significant relationship between the construction operation prompting fall and the degree of injury. In this case, a phi value of .332 denotes a moderate relationship.

Table 20: Degree of injury vs. construction operation prompting fall

Construction operation prompting fall	Nonfatal	Fatal	**Total**
1: Roofing	634 (69.0%)	522 (43.7%)	1156
2: Exterior carpentry	34 (3.7%)	230 (19.2%)	264
3:Specific steel functions including decking	60 (6.5%)	29 (2.4%)	89
4: Other	29 (3.2%)	32 (2.7%)	61
5: Erecting structural steel	73 (7.9%)	238 (19.9%)	311
6: Installing metal siding & water proofing	89 (9.7%)	144 (12.1%)	233
Total	919	1195	2114

As seen in Table 21, fall from the roof is the most frequently occurring fatality causing action (50.2%), followed by fall from/with structure other than roof action (22.9%). According to Table 15, Pearson chi square is “.000”, hence there is a significant relationship between the fatality/injury cause and the degree of injury. A phi value of .251 indicates a weak relationship.

Table 21: Degree of injury vs. fatality /injury cause

Fatality /injury cause	Nonfatal	Fatal	**Total**
1: Collapse of structure	27 (2.9%)	16 (1.3%)	43
2: Fall from /with ladder	129 (14%)	106 (8.9%)	235
3: Fall from roof	536 (58.3%)	600 (50.2%)	1136
4: Fall from / with scaffold, bucket and platform catwalk (attached to the structure)	112 (12.2%)	84 (7.0%)	196
5: Fall through opening	17 (1.8%)	39 (3.3%)	56
6: Fall from /with structure other than roof	65 (7.1%)	274 (22.9%)	339
7: Other	33 (3.6%)	76 (6.4%)	109
Total	919	1195	2114

As shown in Table 22, unguarded/improperly secured platforms, walkways, openings, edges, ladders (38%) are the most fatal category, followed by the “other” category (31.7%). According to Table 15, a weak significant relationship is found between the degree of injury and the environmental factor.

Table 22: Degree of injury vs. environmental factors

Environmental Factors	Nonfatal	Fatal	**Total**
1: Hazardous work surface/housekeeping problems	113 (12.3%)	102 (8.5%)	215
2: Structural failure (other than full collapse)	129 (14%)	75 (6.3%)	204
3: Unguarded/ improperly secured platforms, walkways, openings, edges, ladders	240 (26.1%)	454 (38%)	694
4: Moving flying or falling object	45 (4.9%)	61 (5.1%)	106
5:Wind and other weather related factors	20 (2.2%)	22 (1.8%)	42
6:Materials handling and equipment	55 (6.0%)	57 (4.8%)	112
7: Other	298 (32.4%)	379 (31.7%)	677
8: Chemical and radiation action	0 (0%)	2 (0.2%)	2
9: Miss. Issues of WS/FLC	19 (2.1%)	43 (3.6%)	62
Total	919	1195	2114

Table 23 shows that inappropriate choice/use of equipment, position, material handling, processing is the highest occurring human factor that affects fatal accidents (38.2%), followed by misjudgment of hazardous situation (33.1%). As seen in Table 15, Pearson chi square significance is ".001", hence there is a significant relationship between the human factors and the degree of injury; and a phi value of .101 indicates a weak relationship.

Table 23: Degree of injury vs. human factors

Human factors	Nonfatal	Fatal	**Total**
1: Misjudgment of hazardous situation	315 (34.3%)	395 (33.1%)	710
2: Malfunctioning safety equipment/system (including lockout/logout tag out)	75 (8.2%)	66 (5.5%)	141
3: Distracting actions by others	5 (0.5%)	6 (0.5%)	11
4: Human system malfunction	28 (3.0%)	18 (1.5%)	46
5: Inappropriate choice/use of equipment, position, material handling, processing	281 (30.6%)	456 (38.2%)	737
6: Insufficient engineering and administrative controls	53 (5.8%)	71 (5.9%)	124
7: Others	162 (17.6%)	183 (15.3%)	345
Total	919	1195	2114

4.5.1. LAYERED CROSS TABULATION OF SELECTED VARIABLES

First, layered cross tabulation analysis was performed to examine if safety training and union status had any collective effect on fatality. Second, SIC codes' and union status' collective effect was determined.

As seen in Table 24, there are 1195 fatalities to be analyzed. Among them 793 fatal accidents occurred even though victims received safety training, and 402 victims did not receive safety training. Union workers who did not have safety training (57/85) or (67.1%) died from the fall accidents which indicate a relation between safety training and fatality. Among the nonunion workers there is not a big difference in terms of the percentage between fatal and nonfatal accidents. On the other hand, among the union workers, who did have safety training, fatal accidents are much more frequent than nonfatal ones (76.6% vs. 23.4%). For nonunion workers, who did have safety training there was no significant difference in the numbers of fatal and nonfatal cases. The percentages given in Table 24 are derived by dividing the number in each cell by the total number shown in the rightmost column.

Table 24: Degree of injury vs. union status vs. safety training provided

	Union status	Nonfatal	Fatal	**Total**
No fall safety training provided	Union	28 (33%)	57 (67%)	85
	Nonunion	263 (43%)	345 (57%)	608
Total		291	402	693
Fall safety training provided	Union	84 (23%)	275 (77%)	359
	Nonunion	544 (51%)	518 (49%)	1062
Total		628	793	1696

As shown in Table 25, in considering fatalities, out of 1195 deaths, 594 cases involve roofers and 601 are for steel workers. Of these total fatalities, only 332 (27.8%) are union workers and 72.2% are nonunion. There are a total of 1413 roofers and 594 of them had fatal accidents. Only 55 of the union roofing workers (9.3%) fell victim to fatal accidents, in comparison to 539 (90.7%) nonunion workers. There are a total 701 steel workers, and 601 of them experienced fatality. Only 277 of them (46.1%) were union workers, and 324 (53.9%) were nonunion workers. Nonunion roofers' fatalities add up to 45.1% of the total fall accident deaths. The percentages given in Table 25 are computed by dividing the number in each cell by the total number shown immediately below that number.

The layered cross tab analysis results show that this is a useful technique for extracting detailed and useful relationship information out of the data that goes beyond the regular cross tab analysis.

Table 25: Degree of injury vs. Union status vs. SIC codes

	Union status	Nonfatal	Fatal	**Total**
SIC 1761	Union	77 (9.4%)	55 (9.3%)	132
	Nonunion	742 (90.6%)	539 (90.7%)	1281
	Total	819	594	1413
SIC 1791	Union	35 (35%)	277 (45.4%)	312
	Nonunion	65 (65%)	324 (54.6%)	389
	Total	100	610	701

4.6. CROSS TABULATION OF ROOFER ACCIDENTS (SIC 1761)

Cross tabulation analysis for roofers was performed first on the dichotomous variables shown in Table 26. As seen in this table, chi square significance values are below 0.05 for task assignment, project type, fall safety protection system provided, fall safety system used, and safety training provided. Phi values as before indicate the strength of the relationship between the degree of injury and the variables that are found to be significant. According to the convention adopted in this research, all of the relationships are weak.

Table 26: Cross tabs with degree of injury vs. independent dichotomous variables for roofers

Independent variables	Chi Square Value	df	Significance (p)	Phi or Cramer's V	Odds ratio
Union status	.008	1	.928	-	-
Task assignment	5.278	1	.022	.061	1.56
Project type	15.757	1	.000	.106	1.54
Fall safety protection system provided	23.916	1	.000	-.130	1.76
Fall safety protection system used	27.831	1	.000	-.140	1.85
Safety training provided	28.782	1	.000	-.143	1.82

It is observed in Table 27 for roofer fatalities that 90.7% of them occurred when the victim was a nonunion member. However, there exists no significant relationship between the degree of injury and the union status (See significance >.05 in Table 26).

Table 27: Degree of injury vs. union status for roofers

Union status	Nonfatal	Fatal	Total
Nonunion	742 (90.6%)	539 (90.7%)	1281
Union	77 (9.4%)	55 (9.3%)	132
Total	819	594	1413

As indicated in Table 28, 89.9% of the fatal cases occurred while victims were working on a regularly assigned task. The odds of fatality for roofers when they worked on nonregularly assigned task is 1.56 times higher than the workers who worked on regularly assigned task. The chi square test results in Table 26 shows that there is a significant relationship between the degree of injury and task assignment regularity for the roofers and the level of the strength of this relationship is weak (.061).

Table 28: Degree of injury vs. task assignment for roofers

Task	Nonfatal	Fatal	**Total**
Regular	764 (93.3%)	534 (89.9%)	1298
Nonregular	55 (6.7%)	60 (10.1%)	115
Total	819	594	1413

As shown in Table 29, 65% of the roofers died while performing alteration/ rehabilitation, maintenance/repair, demolition and other project types. Chi square test results in Table 26 shows that there is a significant relationship between the degree of injury and the project type for roofers, and level of strength of this relationship is weak. The odds of fatality when a worker works on project type 2 is 1.54 times higher than the worker works on project type 1 for roofers.

Table 29: Degree of injury vs. project type for roofers

Project type	Nonfatal	Fatal	**Total**
PT1: New project or new addition	373 (45.5%)	208 (35%)	581
PT2: Alteration/rehabilitation, maintenance/ repair, demolition and other	446 (54.5%)	386 (65%)	902
Total	819	594	1413

As seen in Table 30, 72.1% of the fatal cases among roofers occurred when fall protection system is not provided. Chi square test (Table 26) shows that there is a significant relationship between the degree of injury and fall safety system provision for roofers, and the level of strength of this relationship is weak and negative. For roofers, the odds of fatality when the fall protection system is not provided is 1.76 times higher than when the fall protection system is provided (Table 26).

Table 30: Degree of injury vs. fall safety protection system provided for roofers

Fall safety protection system	Nonfatal	Fatal	**Total**
Not provided	487	428 (72.1%)	915
Provided	332	166 (27.9%)	498
Total	819	594	1413

According to the cross tab analysis displayed in Table 31, 73.2% of the fatal cases for roofers occurred while a fall protection system was not used. While in 72.1% of the fatal cases fall safety protection was absent, only 1.1% of the victims had chosen not to use the protective system. The chi square test shows that there is a significant relationship between the degree of injury and fall safety system usage for roofers, and level of strength of this relationship is weak, and negative (-.140). The odds of fatality when the fall protection system is not used is 1.85 times higher than when the fall protection system is used (Table 26).

Table 31: Degree of injury vs. fall safety protection system used for roofers

Fall safety protection system used	Nonfatal	Fatal	**Total**
Not used	489	435 (73.2%)	924
Used	330	159 (26.8%)	489
Total	819	594	1413

Among the roofers, most fatalities occurred even the victim had received safety training (Table 32). The chi square test result shown in Table 26 indicates that there is a significant relationship between the degree of injury and fall safety training for roofers and the level of strength of this relationship is negative weak (-.143). The odds of fatality when the fall safety training is not provided is 1.82 times higher than when the fall safety training is used for roofers (Table 26).

The odds ratio reveals that if the fall safety training is not provided, the odds of fatality is increased by 1.82 for roofers.

Table 32: Degree of injury vs. fall safety training provided for roofer

Safety training provided	Nonfatal	Fatal	**Total**
Not provided	268 (32.7%)	278 (46.8%)	546
Provided	551 (67.3%)	316 (53.2%)	867
Total	819	594	1413

Cross tabulation analysis for roofers was performed separately for the multi-valued categorical variables, and the results are shown in Table 33. As seen in this table, chi square values are below 0.05 for construction end use, fall distance, fatality/injury cause, environmental factors, and human factors. Further, the phi values gauge the strength of the relationship between the degree of injury and the variables found to be significant. According to the convention adopted in this research, all of the relationships are weak.

As seen in Table 34, there were 820 of the cases which had no age information. It should also be noted that there are no nonfatal accident cases observed among the 593 cases; therefore, the cross tab analysis for age is not included in Table 33.

Table 33: Cross tabs with degreee of injury vs. multi – valued categorical variables for roofers

Independent variables	**Chi Square Value**	**df**	**Significance (p)**	**Phi or Cramer's V**
Construction end use	37.707	3	.000	.163
Project cost	3.437	2	1.79	-
Fall distance	105.607	2	.000	.273
Construction operation prompting fall	9.284	5	.098	-
Fatality/injury cause	40.625	6	.000	.170
Environmental factors	59.547	8	.000	.205
Human factors	21.633	6	.001	.101

As seen in Table 34, all of the victims for whom the age is known had fatal accidents. Among them, the age group 2 (between 30 and 50 years of age) was the most fatality prone age group.

Table 34: Degree of injury vs. age for roofers

Age	Nonfatal	Fatal
AG 1 ≤30	0	182 (30.7%)
30<**AG 2** ≤50	0	334 (56.3%)
AG 3>50	0	77 (13.0%)
Total	0	593

According to Table 35, roofer fatalities for commercial and residential construction end use is the highest (76.1%). As mentioned in our univariate frequency analysis discussion, the OSHA standard 03-00-001 prior to December 16, 2010, allowed employers to use alternative methods of fall protection that were specified to them rather than conventional fall protection required by the standard. This new directive which took effect on December 16 2010 enforces that all residential construction employers must now comply with 29 Code of Federal Regulations 1926.501(b) (13). This is expected to provide for better fall protection to construction workers, especially residential roofers. Referring to Table 33, the chi square significance values confirms that there is a significant relationship between the degree of injury and construction end use for roofers, and level of strength of this relationship is weak.

Table 35: Degree of injury vs. construction end use for roofers

Construction end use	Nonfatal	Fatal	**Total**
1: Commercial & residential	715 (87.3%)	452 (76.1%)	1167
2: Industrial	16 (2.0%)	41 (6.9%)	57
3: Heavy civil	1 (0.1%)	4 (0.7%)	5
4: Other	87 (10.6%)	97 (16.3%)	184
Total	819	594	1413

As shown in Table 36, the project cost group 1 (≤50K) is the highest fatality frequency category (48.7%), closely followed by project cost group 2 (between $50,000 and $5 million) with frequency of 45.6%. The chi square result in Table 33 shows that there is not a significant relationship between the degree of injury and the project cost for roofers (p>.05).

Table 36: Degree of injury vs. project cost for roofers

Project cost	Nonfatal	Fatal	**Total**
PC 1 ≤50K	358 (43.7%)	289 (48.7%)	647
50K<**PC 2**<5M	412 (50.3%)	271 (45.6%)	683
PC 3≥5M	49 (6%)	34 (5.7%)	83
Total	819	594	1413

It is seen in Table 37 that among the roofers a fall distance of more than 20 feet is the highest fatality prone category (54.7%). Going back to Table 33, the chi square test shows that there is a significant relationship between the degree of injury and the fall distance for roofers. In addition, the level of strength of this relationship is weak.

Table 37: Degree of injury vs. fall distance for roofers

Fall distance	Nonfatal	Fatal	**Total**
FD 1 ≤10’	178 (22%)	60 (10.1%)	238
10 <**FD 2** ≤ 20’	409 (50%)	209 (35.2%)	618
FD 3 >20’	232 (28%)	325 (54.7%)	557
Total	819	594	1413

As noted in Table 38, roofing is the most frequently occurring construction operation (79%) that prompts fall fatalities among the roofers. Again from Table 33, the chi square test shows that there is no significant relationship between the degree of injury and the construction operation prompting fall for roofers.

Table 38: Degree of injury vs. construction operation prompting fall for roofers

Construction operation prompting fall	Nonfatal	Fatal	**Total**
1: Roofing	624 (76%)	470 (79%)	1094
2:Exterior carpentry	4 (.6%)	6 (1%)	10
3:Specific steel functions including decking	60 (7.4%)	23 (4%)	83
4: Others	28 (3.4%)	24 (4%)	52
5: Erecting structural steel	21 (2.6%)	16 (3%)	37
6: Installing metal siding & water proofing	82 (10%)	55 (9%)	137
Total	819	594	1413

According to Table 39, 74.4% of the fatal cases are caused by falling from the roof. Also, the chi square test shows that there is a significant relationship between the degree of injury and fatality/injury causes for roofers, and the level of strength of this relationship is weak.

Table 39: Degree of injury vs. fatality / injury cause for roofers

Fatality /injury cause	Nonfatal	Fatal	**Total**
1: Collapse of structure	20 (2.4%)	3 (0.4%)	23
2: Fall from /with ladder	117 (14.3%)	61 (10.3%)	178
3: Fall from roof	512 (62.6%)	442 (74.4%)	954
4: Fall from / with scaffold, bucket and platform catwalk (attached to the structure)	109 (13.3%)	41 (6.9%)	150
5: Fall through opening	14 (1.7%)	20 (3.4%)	34
6: Fall from /with structure other than roof	29 (3.5%)	11 (1.9%)	40
7: Other	18 (2.2%)	16 (2.7%)	34
Total	819	594	1413

Looking at Table 40, among roofers, unguarded/improperly secured platforms, walkways, openings, edges, ladders collectively represent the highest fatality rate (38.2%) among the environmental factors, followed by "other" (30.8%). The chi square test result shown in Table 33 again tells us that there is a significant relationship between the degree of injury and environmental factors for roofers, while the level of the strength of this relationship is weak.

Table 40: Degree of injury vs. environmental factors for roofers

Environmental factors	Nonfatal	Fatal	**Total**
1:Hazardous work surface / housekeeping problems	107 (13.1%)	63 (10.6%)	170
2: Structural failure (other than full collapse)	119 (14.5%)	39 (6.6%)	158
3:Unguarded/ improperly secured platforms, walkways, openings, edges, ladders	212 (25.9%)	227 (38.2%)	439
4:Moving flying or Falling object	35 (4.3%)	10 (1.7%)	45
5:Wind and other Weather related factors	19 (2.3%)	12 (2.0%)	31
6:Materials handling And equipment	48 (5.9%)	27 (4.5%)	75
7. Other	262 (32%)	183 (30.8%)	445
8: Chemical and radiation action	0 (0%)	2 (0.3%)	2
9: Miss. Issues of WS/FLC	17 (2.1%)	31 (5.2%)	48
Total	819	594	1413

As shown in cross tabulation Table 41 for human factors inappropriate choice/use of equipment, position, and material handling, and processing come out as the highest fatality frequency category (36%), followed by misjudgment of hazardous situation (34.7%), among the roofers. The chi square test results shown In Table 33 again tells us that there is a significant relationship between the degree of injury and human factors for roofers (1761). The level of strength of this relationship is weak.

Table 41: Degree of injury vs. human factors for roofers

Human factors	Nonfatal	Fatal	**Total**
1: Misjudgment of hazardous situation	285 (34.8%)	206 (34.7%)	491
2: Malfunctioning safety equipment/system (including lockout /logout tag out)	69 (8.4%)	36 (6.1%)	105
3: Distracting actions by others	5 (0.6%)	1 (0.2%)	6
4: Human system malfunction	28 (3.4%)	7 (1.2%)	35
5: Inappropriate choice /use of equipment, position, material handling, processing	244 (29.8%)	214 (36%)	458
6: Insufficient engineering and administrative controls	42 (5.1%)	49 (8.2%)	91
7: Other	146 (17.8%)	81 (13.6%)	227
Total	819	594	1413

4.7. CROSS TABULATION ANALYSIS OF STEEL WORKERS (SIC 1791)

Cross tabulation analysis for steel workers was performed following a similar approach for the one for roofers. Results for the dichotomous variables are presented in Table 42. As seen in this table, chi square values are below 0.05 for only union status and project type. Furthermore, the phi values for all of the relationships indicated weak levels.

Table 42: Cross Tabs with degree of injury vs. independent dichotomous variables for steel workers

Independent variable	**Chi Square Value**	**df**	**Significance (p)**	**Phi or Cramer's V**	**Odds ratio**
Union status	4.269	1	.039	.078	1.58
Task assignment	.153	1	.696	-	-
Project type	6.333	1	.012	.095	4.17
Fall safety protection system provided	.205	1	.651	-	-
Fall safety protection system used	.130	1	.718	-	-
Safety training provided	.291	1	.59	-	-

Table 43 shows that among the steel workers, 53.9% experienced fatal accidents if they are nonunion category. Chi square test results shown in Table 42 shows that there is a significant relationship between the degree of injury and the union status for steel workers and level of strength of this relationship is weak. For steel workers, the odds of fatality when the steel worker is unionized is 1.58 times higher than when the steel worker is not unionized.

This may be considered anomalous, and hence may call for further investigation.

Table 43: Degree of injury vs. union status for steel workers

Union status	Nonfatal	Fatal	**Total**
Union	35 (35%)	277 (46.1%)	312
Nonunion	65 (65%)	324 (53.9%)	389
Total	100	601	701

The cross tabulation results shown in Table 44 indicate that 94% of the fatal cases occurred while victims are working on regularly assigned tasks. Chi square test results in Table 42 reveal that there is not a significant relationship between the degree of injury and task assignment regularity for steel workers (p>.05).

Table 44: Degree of injury vs. task assignment for steel workers

Task assignment	Nonfatal	Fatal	**Total**
Regular	95 (95%)	565 (94%)	660
Non regular	5 (5%)	36 (10.1%)	41
Total	100	601	701

As observed from the cross tabulation in Table 45, fatalities of steel workers most frequently occur at new construction or additions (88.9%) in comparison to alteration/rehabilitations, maintenance/repair, demolition and other (11.1%). For steel workers, the odds of fatality when a steel worker is working on project type 2 is 4.17 times higher than the odds of fatality for workers who work on project type 1.

Pearson chi square is ".000"; hence there is a significant relationship between the project type and the degree of injury. But, phi value is .095 so there is a weak relationship.

Table 45: Degree of injury vs. project type for steel workers

Project type	Nonfatal	Fatal	**Total**
PT 1: New project or new addition	97 (97%)	534 (88.9%)	631
PT2: Alteration/rehabilitation, maintenance/ repair, demolition and other	3 (3%)	67 (11.1%)	70
Total	100	601	701

Table 46 reveals that 55.6% of the fatal cases among steel workers occurred when a fall protection system is not provided. Further, chi square test shows that there is not a significant relationship between the degree of injury and the provision of a fall safety system for steel workers.

Table 46: Degree of injury vs. fall safety protection system provided for steel workers

Fall safety protection system	Nonfatal	Fatal	**Total**
Not provided	58 (58%)	334 (55.6%)	392
Provided	42 (42%)	267 (44.4%)	309
Total	100	601	701

According to Table 47, 57.1% of the fatal cases among steel workers occurred when fall protection system is not used. Since 55.6% of the fatal cases are the ones for which fall safety protection was absent, only 9 victims have chosen not to use the protective system provided. Again, the chi square test shows that there is no significant relationship between the degree of injury and the fall safety system usage by steel workers.

Table 47: Degree of injury vs. fall safety protection system used for steel workers

Fall safety protection system used	Nonfatal	Fatal	**Total**
Not used	59 (59%)	343 (57.1%)	402
Used	41	258 (42.9%)	299
Total	100	601	701

Table 48 shows that the highest fatality occurrence is among the workers who had safety training (79.4%). It is important to note that fatal cases were 86% vs. 14% nonfatal. Chi square test shows that there is no significant relationship between the degree of injury and fall safety training of steel workers (Table 42).

Table 48: Degree of injury vs. fall safety training provided

Safety training provided	Nonfatal	Fatal	**Total**
Not provided	23 (23%)	124 (20.6%)	147
Provided	77 (77%)	477 (79.4%)	554
Total	100	601	701

Cross tabulation analysis for steel workers was performed on separately for the multi-valued categorical variables, and the results are shown in Table 49. As seen in this table, chi square p values are below 0.05 for construction operation prompting fall, fatality/injury cause, and human factors. Phi values further gauge the strength of the relationship between the degree of injury for the variables found to be significant. According to the convention adopted in this research, all of the relationships are weak.

Steel worker age information was missing in 335 cases and all of the known cases were resulted fatal; hence age category is not included in Table 49. The frequencies of the age groups are shown in Table 50.

Table 49: Cross Tabs with degreeeof injury vs. independent multi – valued categorical variables for steel workers

Independent variable	**Chi Square Value**	**df**	**Significance (p)**	**Phi or Cramer's V**
Construction end use	1.988	3	.575	-
Project cost	3.28	2	1.94	-
Fall distance	5.441	2	.066	-
Construction operation prompting fall	11.292	5	.046	.127
Fatality/injury cause	14.84	6	.022	.145
Environmental factors	5.802	7	.563	-
Human factors	12.978	6	.043	.136

As seen in Table 50, among the 701 steel worker accidents only 366 cases have age information. All known cases were fatal. The age group 2 (between 30 and 50) came out to be the most fatality prone group among the steel workers (60.4%).

Table 50: Degree of injury vs. age for steel workers

Age	Nonfatal	Fatal
AG 1 ≤30	0	92 (25.1%)
30<**AG 3** ≤50	0	221 (60.4%)
AG 3>50	0	53 (14.5%)
Total	0	366

According to Table 51, steel worker fatalities for commercial and residential construction end use is the highest (60.9%). Referring to Table 49 the chi square values confirm that there is not a significant relationship between the degree of injury and the construction end use for steel workers (p>.05).

Table 51: Degree of injury vs. construction end use for steel workers

Construction end use	Nonfatal	Fatal	Total
CEG1: Commercial & residential	55 (55%)	366 (60.9%)	421
2: Industrial	8 (8%)	49	57
3: Heavy civil	8 (8%)	50	58
4: Other	29 (29%)	136 (22.6%)	165
Total	100	601	701

As shown in Table 52, the project cost group 2 (between $50,000 and $5 million) is the highest fatality frequency category followed by cost group 3 (more than $5 million). As opposed to roofer accidents, which mostly occurred in cost groups 2 and 1 (less than $50,000), steel worker fatalities mostly occurs in cost group 2 and 3 which suggests that steel workers mostly work in higher budgeted construction projects. The chi square test result in Table 49 shows that there is not a significant relationship between the degree of injury and the project cost of steel workers ($p>.05$) .

Table 52: Degree of injury vs. project cost for steel workers

Project cost	Nonfatal	Fatal	Total
PC 1 ≤50K	4	50 (8.3%)	54
50K<**PC 2**<5M	60	373 (62.1%)	433
PC 3≥5M	36	178 (29.6%)	214
Total	100	601	701

It is seen in Table 53 that among the steel workers, a fall distance of more than 20 feet is the highest fatality category (56.9%). It is a common fact that steel workers mostly work at high elevations. Going back to Table 49 the chi square test shows that there is not a significant relationship between the degree of injury and the fall distance of steel workers (p>.05).

Table 53: Degree of injury vs. fall distance for steel workers

Fall distance	Nonfatal	Fatal	**Total**
FD 1 ≤10’	4 (4%)	45 (7.5%)	49
10 <**FD 2** ≤ 20’	47 (47%)	214 (35.6%)	261
FD 3 >20’	49 (49%)	342 (56.9%)	391
Total	100	601	701

As noted in Table 54, exterior carpentry is the most frequently occurring construction operation that prompts fall fatalities (37.3%), closely followed by erecting structural steel (36.9%). Again from the chi square test shown in the Table 49, we see that there is a significant relationship between the degree of injury and the construction operation prompting fall for steel workers. In addition, the strength of this relationship is weak.

Table 54: Degree of injury vs. construction operation prompting fall for steel workers

Construction operation prompting fall	Nonfatal	Fatal	**Total**
1: Roofing	10 (10%)	52 (8.6%)	62
2:Exterior carpentry	30 (30%)	224 (37.3%)	254
3:Specific steel functions including decking	0 (0%)	6 (1%)	6
4: Other	1 (1%)	8 (1.4%)	9
5: Erecting structural steel	52 (52%)	222 (36.9%)	274
6: Installing metal siding & water proofing	7 (7%)	89 (14.8%)	96
Total	100	601	701

According to Table 55, 43.8% of the fatal cases are caused by falling from/with a structure other than roof. Also, the chi square test shows that there is a significant relationship between the degree of injury and fatality/injury causes for steel workers and the strength of this relationship is weak.

Table 55: Degree of injury vs. fatality/ injury cause for steel workers

Fatality /injury cause	Nonfatal	Fatal	**Total**
1: Collapse of structure	7 (7%)	13 (2.1%)	20
2: Fall from /with ladder	12 (12%)	45 (7.3%)	57
3: Fall from roof	24 (24%)	158 (26.3%)	182
4: Fall from / with scaffold, bucket and platform catwalk (attached to the structure)	3 (3%)	43 (7.1%)	46
5: Fall through opening	3 (3%)	19 (3.6%)	22
6: Fall from /with structure other than roof	36 (36%)	263 (43.8%)	299
7: Other	15 (15%)	60 (9.8%)	75
Total	100	601	701

Looking at Table 56, among the steel workers, unguarded/improperly secured platforms, walkways, openings, edges, ladders collectively represent the highest fatality (37.8%) among the environmental factors, followed by “other” (32.6%), which embody pinch point action, catch point/puncture action, squeeze point action, temperature (+/-) tolerance level, illumination, overpressure/under pressure. The chi square test in Table 49 shows that there is not a significant relationship between the degree of injury and environmental factors for steel workers ($p>.05$).

Table 56: Degree of injury vs. environmental factors for steel workers

Environmental factor	Nonfatal	Fatal	**Total**
1: Hazardous work surface/housekeeping problems	6 (6%)	39 (6.5%)	45
2: Structural failure (other than full collapse)	10 (10%)	36 (6%)	46
3: Unguarded/improperly secured platforms, walkways, openings, edges, ladders	28 (28%)	227 (37.8%)	255
4: Moving flying or falling object	10 (10%)	51 (8.5%)	61
5: Wind and other weather related factors	1 (1%)	10 (1.7%)	11
6: Materials handling and equipment	7 (7%)	30 (4.9%)	37
7. Other	36 (36%)	196 (32.6%)	232
8: Chemical and radiation action	0 (0%)	0 (0%)	0
9: Miss. Issues of WS/FLC	2 (2%)	12 (2%)	14
Total	100	601	701

As shown in the cross tabulation Table 57 for human factors, inappropriate choice/use of equipment, position, and material handling, and processing came out as the highest fatality frequency category (40.3%) followed by, misjudgment of hazardous situation (31.4%) among the steel workers. The chi square test result shown in Table 49 tells us that there is a significant relationship between the degree of injury and human factors for steel workers. The level of strength of this relationship is weak.

Table 57: Degree of injury vs. human factors for steel workers

Human factor	Nonfatal	Fatal	**Total**
1: Misjudgment of hazardous situation	30 (30%)	189 (31.4%)	219
2: Malfunctioning safety equipment/system (including lockout/logout tag out)	6 (6%)	30 (4.9%)	36
3: Distracting actions by others	0	5 (.9%)	5
4: Human system malfunction	0	11 (1.8%)	11
5: Inappropriate choice/use of equipment, position, material handling, processing	37 (37%)	242 (40.3%)	279
6: Insufficient engineering and administrative controls	11 (11%)	22 (3.7%)	33
7: Other	16 (16%)	102 (17%)	118
TOTAL	100	601	701

4.8. SUMMARY OF FINDINGS

4.8.1. CROSS TABULATION FOR WHOLE DATA

There is a statistically significant relationship between union status, SIC code, project type, fall safety protection system provision, fall safety system use, construction end use, project cost, fall distance, construction activity prompting fall, fatality / injury cause, environmental factors, human factors and the degree of injury.

A secondary analysis for multivalued independent variables showed that the relationship between the degree of injury and human factors #2 (malfunctioning safety equipment/system (including lockout/logout tag out)), #4 (human system malfunction), and #5 (inappropriate choice/use of equipment, position, material handling, processing) were significant.

The secondary analysis of individual factors showed that factors #1, #2, #3 and #9 have significant relationship between the degree of injury.

The relationship between the degree of injury and construction operation prompting fall #1(roofing), #2 (exterior carpentry), #3 (specific steel functions including decking), and #5 (erecting structural steel) were significant.

The relationship between the degree of injury and construction cost #1 and #2 were significant.

A majority of fatalities are with nonunion workers 72.2 % versus union 27.8%.

The odds of fatality for unionized workers are 2.77 times higher than the fatality odds for nonunionized workers. This may be considered anomalous, and hence may call for further investigation.

The odds of fatality for the fall safety protection system is not in place is 1.22 times higher than the odds of fatality for fall safety system is provided.

The odds of fatality for a worker who is not using fall safety protection system, is 1.27 times higher compared to when fall safety protection system is used.

The odds of fatality for working on a new project or addition increases the odds of fatality among steel workers and roofers by 1.56 times.

4.8.2. CROSS TABULATION FOR ROOFERS

The odds of fatality when a worker works on project type 2 (alterations/rehabilitation, maintenance/repair demolition and other) is 1.54 times higher than the worker working on project type 1 (new project or addition).

The odds of fatality when fall protection system is not provided is 1.76 times higher than when fall protection system is provided.

The odds of fatality when the fall protection system is not used is 1.85 times higher than when the fall protection system is used.

The odds of fatality when the fall safety training is not provided is 1.82 times higher than when the fall safety training is provided.

The odds of fatality for roofers when they worked on a nonregularly assigned task is 1.56 times higher than the fatality odds for workers working on a regularly assigned

4.8.3. CROSS TABULATION FOR STEEL WORKERS

The odds of fatality when the steel worker is unionized is 1.58 times higher than when the steel worker is not unionized.

The odds of fatality when a steel worker is working on project type 2 is 9.26 times higher than the odds of fatality for workers who work on project type 1.

4.9. LOGISTIC REGRESSION MODELING OF THE WHOLE DATA

Since the response (dependent) variable is of a binary nature (i.e. has two categories - fatal or nonfatal), the logistic regression technique was used to develop models in this study, as explained in the methodology section. The intent was to provide a model that can be used to assess the most important factors contributing to the fatality resulting from fall from elevation based on information extracted from OSHA accident reports. Five dichotomous categorical independent variables were used in the model development process. These were the ones found to be significant in the cross tab analysis. Table 58 lists these variables, their values and types.

Table 58: Logistic regression modeling variables for the whole data

Name of the variables in logistic regression modeling #1	Values	Type of variable
1. Degree of injury Dependent variable	Fatal:1 Nonfatal: 0	Categorical, Dichotomous
2. Union status	Union:1 Nonunion: 0	Categorical, Dichotomous
3. SIC	1761- roofers:1 1791-steel workers: 0	Categorical, Dichotomous
4. Project type	PT 1: new project or new addition PT 2: alteration/rehabilitation, maintenance/repair, demolition and other	Categorical Dichotomous
5. Fall safety protection system is used	Used:1 Not used: 0	Categorical, Dichotomous
6. Safety training and re-training provided	Provided:1: Not provided: 0	Categorical, Dichotomous

The Hosmer and Lemeshow test shows the goodness of fit for the model. It indicates a poor fit if the chi square significance (p) value is less than .05. In this case, p value is .150 and greater than .05, therefore, the data fits the model adequately.

By comparing the observed and predicted results from the model using SPSS program (classification table), it was found that fatality and nonfatality could be correctly predicted in 68.3% of the cases.

Table 59: Logistic regression results based on the whole data

Variables	β	S.E.	Wald	df	p	Exp (β)	95 % C.I. for EXP (β)	
							Lower	Upper
SIC (1791)	2.423	.136	317.237	1	.000	11.278	8.636	14.723
Project type 2	.483	.108	19.948	1	.000	1.621	1.311	2.004
Fall safety protection system used	-.456	.103	19.789	1	.000	.634	.518	.775
Constant	-.457	.092	24.784	1	.000	.633		

For validation of the created model, rv.bernoulli (0.7) was used which selects 70% of the cases and compares the observed and expected values for selected and unselected cases. (SPSS tutorial on logistic regression modeling). The created model predicted fatality on selected cases (70%) and unselected cases (30%) with a percentage of 68.5% and 67.6% respectively. This is an indication of the validation of the model in terms of predicting the outcome.

According to logistic regression results given in Table 59, the observed level of significance for regression coefficients for the three variables were less than .05; the rest of the independent variables' observed level of significance were more than .05. This suggests that these significant three variables were the explanatory variables to be included in the model. As can be observed in the model logistic regression Table 59:

Based on the odds ratio (Exp. β), fatality among steel workers, when the other variables in the model held constant, is 11.278 times higher than odds of fatality for roofers.

The odds of fatality among workers who work on project type 2 (alterations/rehabilitation, maintenance/repair, demolition and other), when the other variables held constant, is 1.621 times higher than odds of fatality for project type 1 which is new project or addition.

The odds of fatality when the fall protection system is used, when the other variables held constant, is .634 times lower than odds of fatality for the fall protection system is not used. Upper and lower limits are given in the table.

4.10. LOGISTIC REGRESSION MODELING OF ROOFERS

The intent was to provide a model that can be used to assess the significant factors contributing to fatality resulting from fall from elevation based on information extracted from OSHA accident report for roofers. Five dichotomous categorical independent variables were used in the model development process. These were the ones found to be significant in the cross tab analysis with the dependent variable being the degree of injury; Table 60 lists these variables, their values and types.

Table 60: Logistic regression modeling variables for roofers (SIC 1761)

Name of the variables in logistic regression modeling #2	Values	Type of variable
1. Degree of injury Dependent variable	Fatal:1 Nonfatal: 0	Categorical, Dichotomous
2. Task regularity	Regularly assigned:1 Non regularly assigned: 0	Categorical, Dichotomous
3. Project type	PT 1: New project or new addition PT 2: Alteration/rehabilitation, maintenance/repair, demolition and other	Categorical Dichotomous
4. Fall safety protection system is used	Used:1 Not used: 0	Categorical, Dichotomous
5. Safety training provided	Provided:1 Not provided: 0	Categorical, Dichotomous
6. Fall safety protection system provided	Provided:1 Not provided: 0	Categorical, Dichotomous

The Hosmer and Lemeshow test result is .247 which is greater than .05, which indicates an adequate goodness of fit for the model. By comparing the observed and predicted results from the model using SPSS it was found that fatality and nonfatality could be correctly predicted in 61.1% of the cases.

Table 61: Logistic regression results based on the roofers data

Variables	**β**	**S.E.**	**Wald**	**df**	**p**	**Exp (β)**	**95 % C.I. for EXP (β)**	
							Lower	**Upper**
Project type 2	.438	.113	15.115	1	.000	1.550	1.243	1.932
Fall safety protection system used	-.456	.125	13.291	1	.000	.634	.496	.810
Fall safety training provided	-.440	.119	13.686	1	.000	.644	.510	.813
Constant	-.166	.111	2.237	1	.135	.847		

For validation of the model, rv.bernoulli(0.7) was used again. The model predicts the fatality on selected cases (70%) and unselected cases (30%) at levels of with 59.6% and 62% accuracy.

According to the logistic regression results presented in Table 61, the observed level of significance for regression coefficients for the three variables were less than 5%, suggesting that these three variables were significant explanatory variables.

The following observations can also be made from Table 61.

The odds of fatality among workers who work on project type 2 (alterations/rehabilitation, maintenance/repair, demolition and other), when the other variables held constant, could be 1.55 times more likely to occur than odds of fatality for project type 1 which is new project or addition.

The odds of fatality when the fall protection system is used, when the other variables held constant, is .634 times lower than odds of fatality for the fall protection system is not used.

The odds of fatality among roofers who had previous safety training, when the other variables held constant, is .644 times lower than the odds of fatality for the ones who has no safety training is provided. Upper and lower limits are given in the table.

4.11. LOGISTIC REGRESSION MODELING OF STEEL WORKERS

The intent was to provide a model that can be used to assess the significant factors contributing to fatality resulting from fall from elevation based on information extracted from OSHA accident reports for steel workers. Two dichotomous categorical independent variables were used in the model development process. These were the ones found to be significant in the cross tab analysis.

Again, the dependent variable is the degree of injury. Table 62 shows both the dependent and the independent variables, their values and types.

Table 62: Logistic regression modeling variables for steel workers

Name of the variables in logistic regression modeling #3	Values	Type of variable
1. Degree of injury Dependent variable	Fatal:1 Nonfatal: 0	Categorical, Dichotomous
2. Union status	Union:1 Nonunion: 0	Categorical, Dichotomous
3. Project type	PT 1: New project or new addition PT 2: Alteration/rehabilitation, maintenance/repair, demolition and other	Categorical Dichotomous

The Hosmer and Lemeshow test result value is .853 which is greater than .05 and verifies an adequate goodness of fit for the model. By comparing the observed and predicted results from the model using SPSS. it was found that fatality and nonfatality could be correctly predicted in 85.7% of the cases.

Table 63: Logistic Regression results based on the steel workers data

Variables	**β**	**S.E.**	**Wald**	**df**	**p**	**Exp (β)**	**95 % C.I. for EXP (β)**	
							Lower	**Upper**
Union status	.494	.226	4.773	1	.029	1.639	1.052	2.553
Project type 2	1.445	.601	5.773	1	.016	4.242	1.305	13.788
Constant	1.503	.139	117.239	1	.000	4.493		

For validation of the model, rv.bernoulli (0.7) was used one more time. The selected cases are 85.1% and unselected cases are 87.4%, which indicates that the model has a good fit and is predicting correctly. This validates the model.

According to logistic regression results displayed in Table 63 the observed level of significance for regression coefficients for the two variables were less than .05

suggesting that these two variables were significant explanatory variables. We further observe from Table 63 the following:

The odds of fatality for steel workers who are union members, with the other constant variables in the model, is 1.639 times higher than the odds of fatality for workers who are nonunion. This is an anomaly that needs further research.

The odds of fatality among steel workers who work on project type 2 (alterations/rehabilitation, maintenance/repair demolition and other), with the other constant variables in the model, is 4.242 times higher than the odds of fatality for the workers who work on “Project type 1” (new construction or addition).

4.12. SUMMARY OF FINDINGS

4.12.1. LOGISTIC REGRESSION MODELING FOR WHOLE DATA

Based on Exp. β, the odds of fatality among the steel workers, when the other variables in the model are held constant, is 11.28 times higher than odds of fatality for roofers.

The odds of fatality among workers who work on project type 2 (alterations/rehabilitation, maintenance/repair, demolition and other), when the other variables are held constant 1.62 times higher than odds of fatality for project type 1 which is new project or addition.

The odds of fatality when the fall protection system is used, when the other variables are held constant, is .63 times the odds of fatality for the fall protection system is not used.

4.12.2. LOGISTIC REGRESSION MODELING FOR ROOFERS

Fatality among workers who work on project type 2, when the other variables are held constant, are 1.55 times more likely to occur than fatality for project type 1.

The odds of fatality when the fall protection system is used, when the other variables are held constant, is .63 times the odds of fatality when the fall protection system is not used.

The odds of fatality among roofers who had previous safety training, when the other variables are held constant, is .64 times the odds of fatality for those for whom no safety training is provided.

4.12.3. LOGISTIC REGRESSION MODELING FOR STEEL WORKERS

The odds of fatality for steel workers who are union members, with the other constant variables in the model, is 1.639 times higher than the odds of fatality for workers who are nonunion. This is an anomaly that needs further research.

The odds of fatality among steel workers who work on project type 2, with the other constant variables in the model, is 4.242 times higher than the odds of fatality for the workers who work on project type 1.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to identify those variables contributing to fall accidents for roofers and steel workers and to analyze these variables to establish the relationships between them. Predictive models for accident severity based on the contributing significant independent variables were also constructed as part of the study. Comparisons were drawn between the two trades.

Major findings of this study were that; union status, task regularity, project type, construction end use, SIC code, environmental factors, fall distance, age of the worker, construction operation that prompts the fall, human factors, fatality/injury cause, fall safety system provision, fall safety system provision usage, fall safety training provisions were identified as variables potentially contributing to determination of accident severity (fatality vs. nonfatality)

Univariate analysis for the **whole data** indicated the following highest frequency/occurrences:

Project type: New project or addition.

Construction end use: Residential and commercial.

Victim age group: 2 (50≥AG2>30).

Project cost group 2: ($50K<PC2≤ $5M).

Fall distance: Over 20 feet.

Construction activity prompting fall: Roofing operation

Union status: Nonunion workers

Environmental factors: Unguarded/improperly secured platforms, walkways, openings, edges and ladders.

Task assignment: Regularly assigned task.

Human factors: Inappropriate choice/use of equipment, position, material handling, or processing.

Fall safety protection system provision and usage: Not provided and not used.

Fall safety training provision: Provided

SIC Code: Roofers

Results were similar for data pertaining to just roofers and just steel workers, except for the following:

Project type: New project or addition for roofers, alterations/rehabilitation, maintenance/ repair demolition and other for steel workers.

Project cost: Less than $50,000 for roofers, more than $50,000 to $5 million for steel workers.

Construction operation prompting fall: Roofing for roofers; structural steel erection for steel workers.

Fatality/injury cause: Fall from the roof for roofers, fall from/with structure other than roof for steel workers.

Cross tab analysis for whole data indicated that there were significant relationships between the degree of injury and SIC code, union status, environmental factor, project type, project cost, fall distance, construction activity prompting fall, the provision of the fall safety protection system , the fall safety protection system usage, human factors, fatality/injury cause, construction end use.

For the roofers there were a statistically significant relationship between the degree of injury and task regularity, project type, fall safety system provision, fall safety system usage, fall safety training, construction end use, fall distance, fatality/injury cause, environmental factors, and human factors.

For the steel workers there were a statistically significant relationship between the degree of injury and union status, project type, construction operation prompting fall, fatality/injury cause, and human factors.

Based on logistic regression model for the whole data:

- Steel workers are more susceptible to fatal accidents than roofers.
- Project type 1 increases the fatality risk for workers compared to project type 2.
- Not using the fall safety protection system increases the odds for worker fatality.

The model for the roofers showed that:

- Roofers are more susceptible to fatal accidents while working on project type 2 as compared to project type1.
- Safety training for roofers has a lowering effect on the odds of fatality.

For steel workers, the model showed that:

- Unionized steel workers are more susceptible to fatal accidents than nonunion.
- Working on project type 2 increases the odds for steel worker fatality as compared project type 1.

Finally, this research study indicated that the multivariate analysis approach taken and the associated methodologies employed produce meaningful and beneficial results for improving our understanding of the factors contributing to fall accidents involving roofers and steel workers.

APPENDIX - A : SAMPLE ACCIDENT REPORT

Return to Result Page

Accident: 200460814 - Employee Killed In Fall From Steel Structure

Accident: 200460814 -- Report ID: 0111400 -- Event Date: 08/01/2000

Inspection	Open Date	SIC	Establishment Name
302922836	08/01/2000	1791	Rescue Welding, Incorporated

Employee #1, an iron worker, was welding on the 19th floor of a steel structure when he lost his balance and fell to the fifth floor roof. He was killed.

Keywords: fall, lost balance, welder, construction, iron worker, erection process, steel erection, fall protection, work rules

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Commercial building	New project or new addition	$20,000,000 and over	36	460	X

	Inspection	Age	Sex	Degree	Nature	Occupation	Construction
1	302922836			Fatality	Bruise/Contus/Abras	Occupation not reported	**FallDist**: 140 **FallHt**:140 **Cause**: Erecting structural steel **FatCause**: Fall from/with structure (other than roof)

Return

Inspection Nr	302922836
Investigation Nr	200460814
Line Nr	1
Age	
Sex	
Nature of Injury	Bruise/Contus/Abras
Part of Body	Bodysystem
Source of Injury	Bodily Motion
Event Type	Fall(From Elevation)
Environmental Factor	Other
Human Factor	Safety Devices Removed/Inoper.
Occupation	Occupation not reported
Degree of Injury	Fatality
Task Assigned	Task regularly assigned

Inspection: 302922836 - Rescue Welding, Incorporated

Inspection Information - Office: South Boston

Nr: 302922836 Report ID:0111400 Open Date: 08/01/2000

Rescue Welding, Incorporated
One Avery Street
Boston, MA 02111 Union Status: Union
SIC: 1791/Structural Steel Erection
Mailing: 370 Main Street, Somersworth, NH 03878

Inspection Type: Accident
Scope: Partial Advanced Notice: N
Ownership: Private
Safety/Health: Safety Close Conference: 09/20/2000
Emphasis: S:Construction,S:Construction Fatalities Close Case: 11/13/2000

Optional Information: Type	ID	Value
N	1	302922836

Related Activity: Type	ID	Safety	Health
Accident	100460617		

Violation Summary

	Serious	Willful	Repeat	Other	Unclass	Total
Initial Violations	2					2
Current Violations	2					2
Initial Penalty	12000					12000
Current Penalty	8400					8400
FTA Amount						

Violation Items

#	ID	Type	Standard	Issuance	Abate	Curr$	Init$	Fta$	Contest	LastEvent
1.	01001	Serious	19260105 A	09/28/2000	10/03/2000	$5900	$7000	$0		I - Informal Settlement
2.	01002	Serious	19261053 B06	09/28/2000	10/03/2000	$2500	$5000	$0		I - Informal Settlement

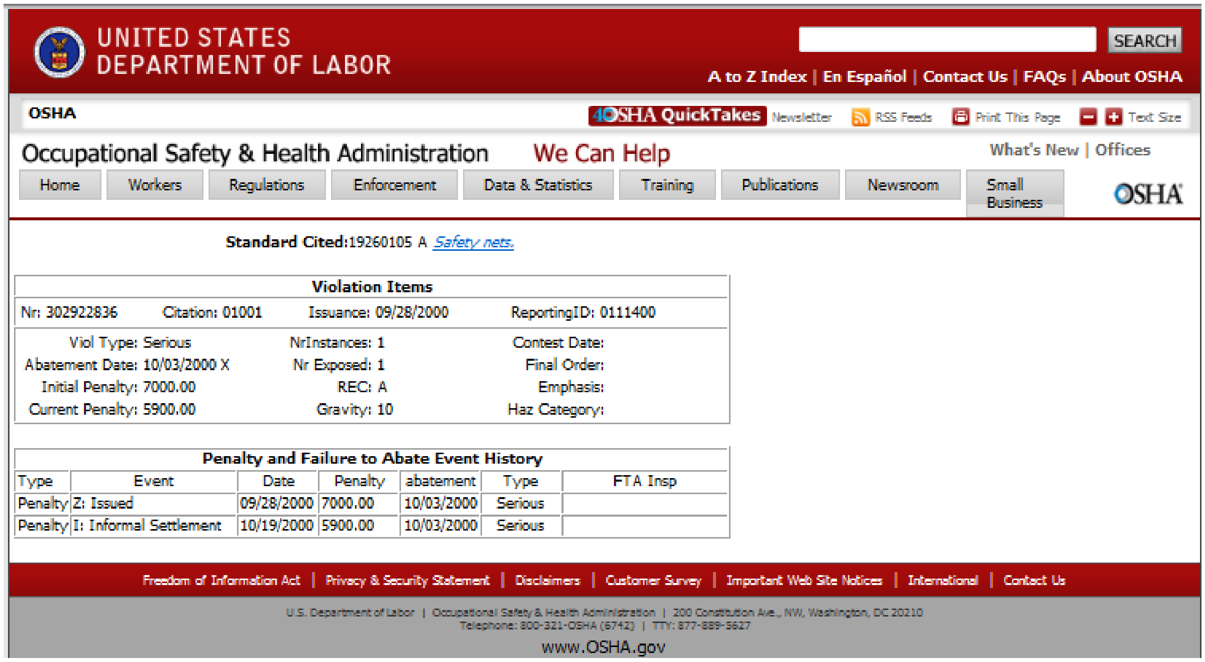
Accident Investigation Summary

Summary Nr: 200460814 Event: 08/01/2000 Employee Killed In Fall From Steel Structure

Employee #1, an iron worker, was welding on the 19th floor of a steel structure when he lost his balance and fell to the fifth floor roof. He was killed.

Keywords: fall, lost balance, welder, construction, iron worker, erection process, steel erection, fall protection, work rules

	Inspection	Degree	Nature	Occupation
1	302922836	Fatality	Bruise/Contus/Abras	Occupation not reported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Standard Cited:19260105 A *Safety nets.*

Violation Items			
Nr: 302922836	Citation: 01001	Issuance: 09/28/2000	ReportingID: 0111400
Viol Type: Serious	NrInstances: 1	Contest Date:	
Abatement Date: 10/03/2000 X	Nr Exposed: 1	Final Order:	
Initial Penalty: 7000.00	REC: A	Emphasis:	
Current Penalty: 5900.00	Gravity: 10	Haz Category:	

Penalty and Failure to Abate Event History

Type	Event	Date	Penalty	abatement	Type	FTA Insp
Penalty	Z: Issued	09/28/2000	7000.00	10/03/2000	Serious	
Penalty	I: Informal Settlement	10/19/2000	5900.00	10/03/2000	Serious	

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Standard Cited:19261053 B06 *Ladders.*

Violation Items			
Nr: 302922836	Citation: 01002	Issuance: 09/28/2000	ReportingID: 0111400
Viol Type: Serious	NrInstances: 1	Contest Date:	
Abatement Date: 10/03/2000 X	Nr Exposed: 1	Final Order:	
Initial Penalty: 5000.00	REC:	Emphasis:	
Current Penalty: 2500.00	Gravity: 10	Haz Category:	

Penalty and Failure to Abate Event History

Type	Event	Date	Penalty	abatement	Type	FTA Insp
Penalty	Z: Issued	09/28/2000	5000.00	10/03/2000	Serious	
Penalty	I: Informal Settlement	10/19/2000	2500.00	10/03/2000	Serious	

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APPENDIX - B : OSHA'S DEFINITIONS FOR ACCIDENT FACTORS

Summary Number	Provides a unique identifier for the accident investigation. This investigation may be linked to several inspections, e.g., if there were multiple contractors at a construction site.
Event description	Provides a short one line description of the accident.
Event date	Indicates the date on which the accident occurred.
State	Indicates the state in which the accident occurred
Degree of injury	Indicates whether the injured person was killed, hospitalized, or non-hospitalized injury.
Union status	Indicates if the victim was a trade union member or not
Task	Indicates if the victim was working at regularly assigned task or not
Environmental factors	Physical factors that effect the victim
Human factors	Indicates the human factors that effect the accident .
SIC code	Indicates the 4-digit Standard Industrial Classification Code from the 1987 version SIC manual which most closely applies.
Construction end use	Indicates the end-use of the structure being built
Nature of the injury	Indicates the nature of the injury
Project type	Indicates the project being a brand new or addition / alteration or demolition
Event type	Indicates the type of the event that caused the accident
Project cost	The sum total of all funds required to complete a total construction activity
Fall distance	Distance of fall
Fall height	Height of person when fell
Non-building height	Height in feet when not a building
Construction operation cause	Construction operation that the victim was working on just before the accident (prompting the accident)
Fatality cause	The causal action of the fatality
Age	Age of the victim
Sex of the victim	Indicates the sex of the injured person.

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ABSTRACT

**ANALYSIS AND MODELING OF
ROOFER AND STEEL WORKER FALL ACCIDENTS**

by

HULYA CAKAN

August 2012

Advisor: Dr. Mumtaz Usmen

Major: Civil and Environmental Engineering

Degree: Doctor of Philosophy

There are more than nine million construction workers in the US. Roofers and steel workers are the highest risk construction trades according to BLS, and fall from elevation accounts for a large percentage of fatalities and injuries among the construction trades.

In this study, 2114 OSHA accident case reports involving roofers and steel workers were reviewed to identify and analyze the factors contributing to construction fall accidents. Using data for the years between 1994 and 2008, the relationships between these factors were determined and further studied to develop predictive models. Univariate frequency, cross tabulation and logistic regression analyses were used to estimate the effect of the statistically significant factors on the degree of injury (fatality vs. nonfatality)

Chi square tests on the entire data showed that there is a significant relationship between the degree of injury and union status, SIC code, construction operation prompting fall, environmental factor, human factor, project type, construction end use,

safety protective system provision, safety protective system usage, fall distance, and fatality/injury cause.

Logistic regression model created for the combined SIC Codes of 1761 and 1791 showed that among the six independent dichotomous variables only four were significantly associated with the degree of injury. These factors were project type, SIC code, safety training and safety protection system usage.

Two separate logistic regression models, one for roofers and another for steel workers were also developed. The roofers' model showed that among the five independent categorical dichotomous variables only three showed significant association with injury severity. These were project type, safety training, and safety protection system usage. The steel worker model showed that only two independent variables had significant association with the degree of injury, and they were union status and project type.

The study showed that cross tabulation analysis and logistic regression modeling can be used for analyzing data on construction fall accidents in a meaningful way, producing useful results.

AUTOBIOGRAPHICAL STATEMENT

Hulya Cakan is an architect with more than fifteen years of experience. She holds a MSCE degree with specialization in Construction Management from Wayne State University (WSU), Detroit, Michigan, and a previous master degree on Architectural Design from Mimar Sinan University, Istanbul, Turkey.

Her experiences include new communities, mixed-use; residential, commercial buildings, church, school, public park and residential renovations.

She has worked as a staff architect, project manager and consultant for Hanahan/Strollo Associates at Ohio, Concrete Services Network at Michigan, Wilcox Associates at Michigan, Professional Contracting Consultants (PCC) at Michigan, Emlak Bank Design and Construction Company at Istanbul and Kutlutas Design and Construction Company in Istanbul.

She has compiled a broad range of experiences providing planning, design and coordination services for a wide variety of project types including Northland Credit Union Building, Michigan; Piper School renovation and addition, Michigan; Grand Lake Church addition, Michigan; Ashtabula County Medical Office building, Ohio; North Side Hospital, adult Psychiatry section renovation, Ohio; Phar - Mor drug store chain renovation, Ohio, Florida, Pennsylvania; Emlak Bank Branch renovations, Istanbul; Bahcesehir new community design, Istanbul; Halkali and Atakoy high rise housing projects, Istanbul.

She worked as an associate professor in the College for Creative Studies, Detroit MI between 2004 and 2012. She has also taught as an adjunct professor at Wayne State University since 2004, specializing AutoCAD and BIM/Revit software applications in civil engineering and construction.