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# Analysis Of Fatal And Nonfatal Accidents Involving Earthmoving Equipment Operators And On-Foot Workers

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# ANALYSIS OF FATAL AND NONFATAL ACCIDENTS INVOLVING EARTHMOVING EQUIPMENT OPERATORS AND ON-FOOT WORKERS

by

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# DEDICATION

Dedicated to my family…

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# INTRODUCTION

## 1.1 Background

Heavy construction equipment is heavy-duty vehicles which are specially designed for performing immense tasks under enormous power. Heavy construction equipment has provided significant benefits to mankind since the first earthmoving machine was introduced in 1835. With the help of these machines, modern civilizations have been established; mankind has been able to create remarkable structures like roads, dams, canals, skyscrapers, etc. They are essential contributors to mankind's modern lifestyle. Gransberg et. al. (2006) tabulated a list of major types of construction projects, the levels of typical heavy construction equipment used, and examples of the work activities performed by these machines (Table 1).

Table 1: Construction Activities and Equipment

| Types of Construction | Level of Use | Work Activities |
| --- | --- | --- |
| Residential | Light | Finish site work, excavation, ground material moving, up to three story lifting, pneumatic assembly tools |
| Commercial | Moderate | Rough and finish site work, stabilizing and compacting, multiple story material lifting, ground and on structure material moving |
| Industrial | Heavy | Large volume rough finish and site work, stabilizing and compacting, ground and on structure material moving, multiple |
| Highway | Intense | Mass dirt and material excavating and moving, stabilizing and compacting, ground material moving and hoisting, miscellaneous |
| Specialty | Intense | Pipeline, power line, steel erection, railroad, offshore, pile driving, logging, concrete pumping, boring, etc. |

Numerous types of heavy construction equipment are available for use to contractors from different industries, such as mining and construction, for performing a wide variety of work activities. Different types of heavy construction equipment are used in different types of projects, or work activities at different levels. These equipment include but are not limited to backhoes, excavators, scrapers, front-end loaders, graders, bulldozers, dump trucks, compactors, asphalt pavers, rollers, concrete mixers, bobcats, tractors, haulage vehicles, water trucks, and others. Table 2 presents a matrix of equipment type versus equipment function.

Table 2: Equipment Function and Equipment Types

| Equipment Function / Equipment Type | Backhoe | Bulldozer | Excavator | Scraper | Front-end Loader | Grader | Cranes | Dump Trucks |
|---|---|---|---|---|---|---|---|---|
| **Excavating** | X | | X | | | | | |
| **Loading** | X | | X | | X | | | |
| **Hauling** | X | | X | X | X | | | |
| **Hauling LD** | | | | | | | | X |
| **Grading** | | X | | X | | X | | |
| **Hoisting** | X | | X | | | | X | |

In today's growing construction industry, mankind's needs and imagination have forced equipment manufacturers to improve their equipment. These benefits sometimes mean more powerful, bigger, and faster equipment; therefore, with the help of advancing technology new and more powerful and productive equipment are being developed. This dramatically increased productivity rate also makes these machines more essential on construction sites. However, these benefits bring dangers; due to their size, the nature of their operation and their power, heavy construction equipment can also become a life threatening concern for those who operate them and work around them. Ever since machinery was first developed, a heavy price in injuries and damages has been paid for the convenience. In the early days of the Industrial Revolution when labor was cheap, little regard was paid to the pain and suffering of injured workers. However, the late 19th Century saw great changes in social attitudes and a growing recognition of the value of the people who worked the machines. (Ridley and Pearce, 2006)

**1.1.1 Construction Safety and Accident Analysis**

According to the Census Bureau more than six hundred thousand establishments employ about six million employees who build and maintain workplaces, houses, and other structures in the US Construction Industry - NAICS 23. (http://www.census.gov/econ/susb/) This number represents about five percent of all U.S. workers and makes the construction industry one of the largest industry sectors in the United States.

Construction jobs remain one of the most dangerous occupations in the American economy due to their variable, complex tasks and activities. Workers on construction sites often find themselves facing dangerous and life-threatening conditions. MacCollum (1995) pointed out that the US construction industry accounts for approximately 7% of the total workforce; but construction worker deaths account for about 20% of all industrial fatalities. Having more than one activity and multiple trades on a construction site at the same time increase the risk of an accident that can lead to an injury or a fatality.

Numerous studies similar to MacCollum's have been conducted by various researchers in order to shed some light not only on the construction industry, but also on other industries over the past two decades. (Abdelhamid and Everett, 2000; Cheng et. al., 2010; Huang and Hinze, 2003; Mohan and Zech, 2005; Baradan and Usmen, 2006; Davies et. al, 1998; Beavers et. al. 2006)

In the United States, concern over the frequency and extent of industrial accidents and health hazards 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 consistent 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)

#### 1.1.1.1 OSHA Integrated Information Management System

OSHA and other agencies have established the necessity for collecting and managing safety information systems for the purpose of planning, managing, tracking and reporting, and providing services and assistance. Thus, the Integrated Management Information System (IMIS) was developed in 1983 as a result of the Occupational

Safety and Health Act of 1970, 29 USC 657, Section 8, and has been operational since 1984. This database is designed and administered by OSHA as an information management tool. It contains work-related accident investigation and workplace inspection reports, standards cited, citations issued, and penalties assessed, as prepared by OSHA compliance officers from the local federal or state office in the geographical area where the activity occurred. (http://www.osha.gov/pls/imis/establishment.html)

Reporting and recording these accidents is mandated by law. OSHA regulation 1904.39(a) mandates that within eight (8) hours after the death of <u>any</u> employee from a work-related incident, or the in-patient hospitalization of <u>three or more employees</u> as a result of a work-related incident, the employer must orally report the accident by telephone or in person to the Area Office of the Occupational Safety and Health Administration (OSHA) that is nearest to the site of the incident (http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12783)

Additionally, establishments are also required to keep records of these recordable injuries and fatalities in standardized logs, commonly known as OSHA logs 300 and 300A. Title 29 of the Code of Federal Regulations; OSH Act section 8(c)(2) and section 24(a) states that "…other than minor injuries requiring only first aid treatment, and which do not involve medical treatment, loss of consciousness, restriction of work or motion or transfer to another job. Consequently, a work-related injury must involve at least 1 of these 4 conditions before it is deemed recordable'' (Recordkeeping Guidelines for Occupational Injuries & Illnesses, 1997).

Hinze and Teizer (2011) explained that the OSHA log data provides a wealth of accident information and the contents found within it allow for a single point of information for identifying exactly what it is that should be addressed in order to reduce injury frequencies.

The IMIS database has all work-related accident investigation reports which are inspection information of workplace accidents where there has been a fatality or catastrophe (three or more worker hospitalizations resulting from a work-related accident) and hospitalized cases of recordable injuries. These reports include information such as the date/time of the accident, a short description of the accident, information on the injured worker (age, gender, occupation and union status), nature of the injury, source of the injury, causal factors (human factor, environmental factor), and results of the inspection including all standards violated, abatement dates, and any penalties assessed. It should also be noted that if there was an objection to these citations and OSHRC decides on deletion of these violations after reviewing the case, these violations are marked as deleted in the investigation reports.

Construction sites are unique places which include many inherently hazardous tasks in challenging conditions. According to the Bureau of Labor Statistics' preliminary report (BLS, 2012), about 16 percent of all work-related fatalities occurred in the construction industry in 2011; of the 4,609 fatal resulted workplace accidents overall in 2011, 721 deaths occurred in the construction industry. That is a fatality rate of 8.9 per 100,000 employed in the year 2011, which is slightly lower than 2010 (Figure 1). These numbers also make the construction industry the second most dangerous industry close behind the transportation and warehousing industries in the United States.

According to OSHA, among all fatalities, falls are the leading cause of death in construction jobs. In 2010, 35 percent of the fatal accidents in the construction industry involved falls, slips and trips and about 10 percent were identified as being struck-by objects or equipment.

According to electronic educational material published by OSHA approximately 75% of struck-by fatalities involve heavy equipment. Also, in the same source it mentioned that one in four “struck-by vehicle” accidents resulting in a fatality involves construction workers, more than any other occupation. (http://www.osha.gov/SLTC/etools/ construction/struckby/mainpage.html)

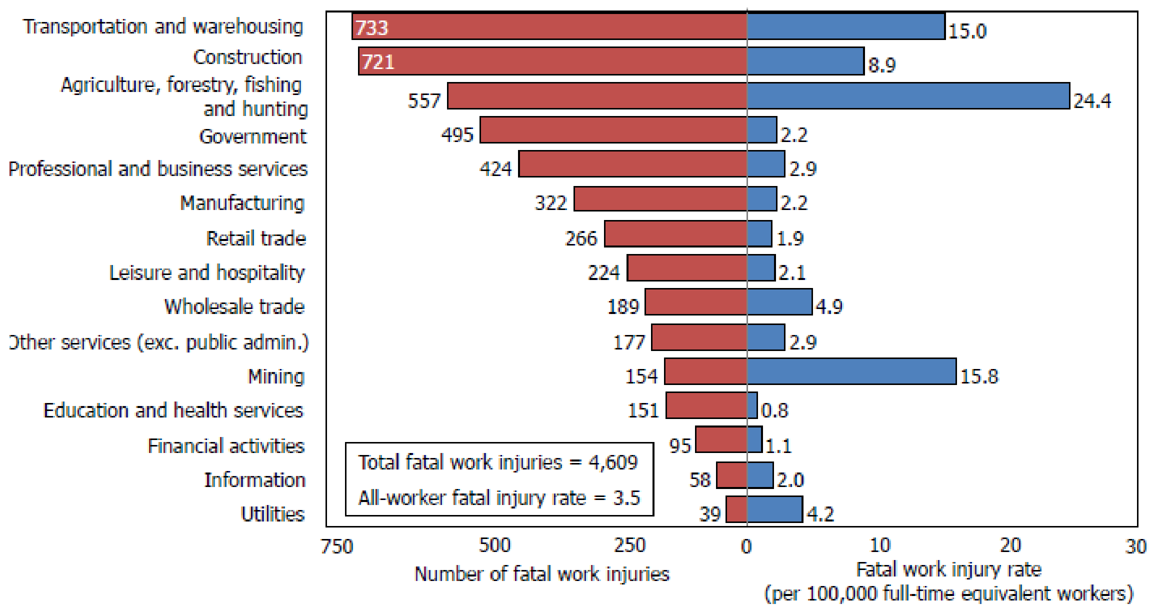


Figure 1: BLS Fatality Statistics – 2011

The information published by the Bureau of Labor Statistics (BLS, 2012) also indicates that the construction industry has a high non-fatal occupational injury incidence rate; this figure was 3.9 per 100 full-time workers in the year 2010. (Figure 2)

These incidence rates represent the number of injuries and illnesses per 100 full-time workers and were calculated as:$(\frac{N}{EH}) \times 200{,}000$ , where N represents the number of injuries and illnesses, EH (employee hour) is the total hours worked by all employees during the calendar year and 200,000 is the base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year).

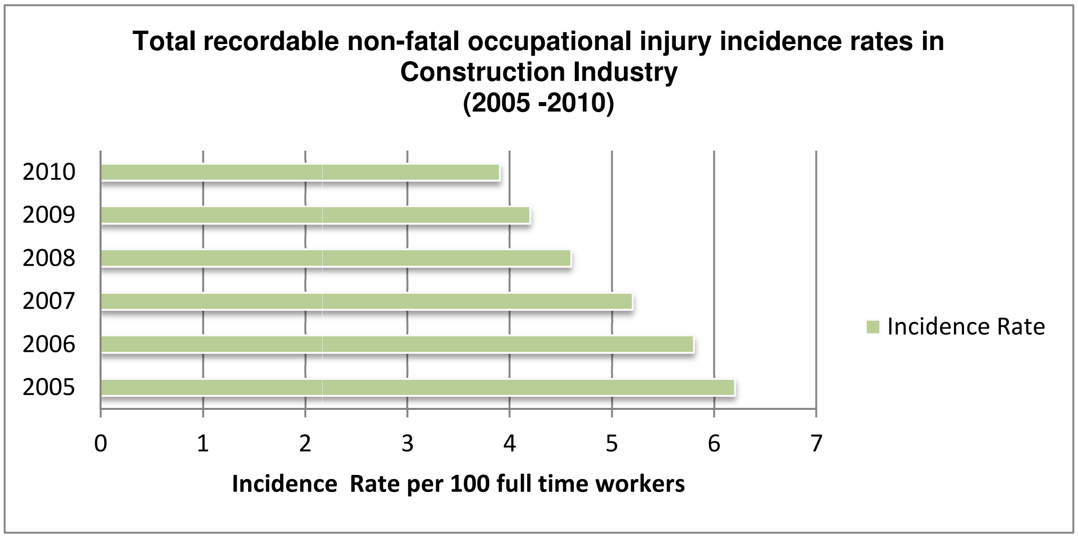


Figure 2 : BLS Injury and Illness Statistics – 2010

### 1.1.2 Heavy Construction Equipment Characteristics and Safety

Most heavy construction equipment have to operate on work sites within close proximity to workers on foot, presenting a common hazard. The most common causes of heavy construction equipment accidents resulting in fatalities and injuries are categorized by OSHA as follows:

- Being caught in/between
- Being struck-by equipment/falling objects (loads, attachments)
- Crushing/being run-over of non-operator by operating construction equipment

- Crushing/being run-over/being trapped of operator by operating construction equipment
- Crushing/being run-over by construction equipment during maintenance
- Falling from vehicle
- Electrocution, fire

Caught-in/between injuries mostly result from workers being caught under overturned equipment or in moving equipment parts. (Hinze et. al., 2005)

Construction workers can be hit due to a construction site's unique design and space configuration, and workers are at risk by working around, or being near, heavy construction equipment while they are operating. Struck-by accidents take place any time a worker is struck or hit by any type of equipment, moving load/material, attachment, and object (Hinze et. al., 2005). These accidents may also involve trench cave-ins when safe work practices are not followed during trench excavation work; for example, cave-ins due to the weight or vibration of heavy construction equipment, being placed too close to the edge of a trench account for struck-by accidents. Also, one other common scenario is heavy construction equipment falling into a trench on top of the workers working in the trench.

Crushing/being run-over of on-foot worker by operating construction equipment occurs when they are run over or crushed between the equipment and ground, or another object, by operator controlled heavy construction equipment (Schriver and Cressler, 2008). Construction sites are typically crowded with equipment and workers on foot. A majority of the fatalities involving heavy construction equipment occur while the equipment is backing up. Struck-by accidents due to back-up motion by equipment is one of the common accidents on construction sites (Ruff, 2004). Poor sight lines and low visibility are inherent in some equipment used on construction projects and in industrial workplaces. This is especially true when the equipment is backing up or moving in areas where space is limited and the turning radius is tight. Warning devices, such as back-up alarms and/or flashing lights, are provided on some mobile equipment, but this is not always sufficient to ensure worker protection, such as on projects where there are many number of equipment, constant movement, and high noise levels. Proper site planning, traffic control systems and worker training are the best ways to reduce accidents where vehicles and employees must work in the same area.

Being crushed/run over/trapped of the operator by operating heavy construction equipment mostly involves equipment operators and includes rollovers and catching the body in equipment or between equipment and the ground or other object while operating the equipment (Schriver and Cressler, 2008). Being crushed/run-over by construction equipment during maintenance includes equipment/attachments falling on a worker/operator while assembling or disassembling equipment (Schriver and Cressler, 2008).

Falls from vehicles or equipment can occur while in motion or at rest (Schriver and Cressler, 2008). Electrocution and fire accidents involve contact with overhead/underground powerlines or gas lines when safe work practices are not followed during excavation, loading or rigging activities.

As discussed, the hazards associated with heavy construction equipment are broad in nature and show commonality among all equipment. The literature review to date reveals that studies investigating heavy construction equipment have vastly focused on all heavy construction equipment in general. Furthermore, it was found that the identified studies have focused on the event type rather than concentrating on specific equipment type. All these factors reveal an area where safety improvements can be made by analyzing specific equipment types by distinguishing between accidents involving different work and equipment categories. Given the fact that earthwork is the most common work type that is inherently a part of every construction site and is an area where limited research information is available, four earthmoving equipment types, including backhoe, bulldozer, excavator, and scraper, were selected for this study. There are other equipment in the category of heavy construction equipment, such as cranes and dump trucks, front-end loaders and graders. However, cranes and dump trucks were eliminated from the scope of this study because they perform somewhat different functions. For example, cranes are mainly used for hoisting loads, and dump trucks are for long distance hauling of materials. Then again, the function performed by front-end loaders and graders overlaps with bulldozers and backhoes, justifying the elimination of these equipment from the research scope as well.

Specific mishaps involving backhoe accidents, bulldozer accidents, excavator accidents and scraper accidents are presented below.

**1.1.2.1 Backhoe Safety**

Backhoes are multipurpose machines that can handle a wide variety of tasks on construction sites. A typical backhoe has outriggers, a hydraulic loader bucket in the front, and a hydraulic digging bucket attached to a dipper and a boom in the rear (Figure 3); one can say that backhoes are a combination of a front-end loader and an excavator. The loader bucket moves vertically where as the rear bucket moves vertically and horizontally (left to right). For most jobs backhoes are used in the stationary state; however, they are also mobile. Tasks they are used for include but are not limited to trench excavation, loading, moving material such as rocks or dirt, and rigging (Nunnally, 2000).


Figure 3: A typical backhoe and its parts
(Photo courtesy of Caterpillar)

Backhoe accidents can be a result of struck-by action, rollovers, electrocutions, and run-overs. The most common forms of these accidents involve workers who operate them or work in close proximity to them, involving being struck by the digging bucket or dipper arm, by the equipment itself or by the material it carries. The swing radius, also called the danger zone, is very important to prevent struck-by accidents. The backing maneuver is also dangerous for workers who work in the path (equipment's direction of movement).

**1.1.2.2 Bulldozer Safety**

A bulldozer is a wheeled or a continuous tracked (crawler) tractor equipped with a blade. It is typically equipped at the rear with a ripper to loosen densely-compacted materials (Figure 4). Bulldozers are used to build access roads; remove dirt or topsoil, push large quantities of gravel, rubble, or other such material; dig out trees; and doing leveling and backfilling jobs as well as pulling/pushing other equipment when it is needed. Bulldozers don't operate in a stationary condition; they are mobile equipment, which moves back and forth with a certain speed during activities.

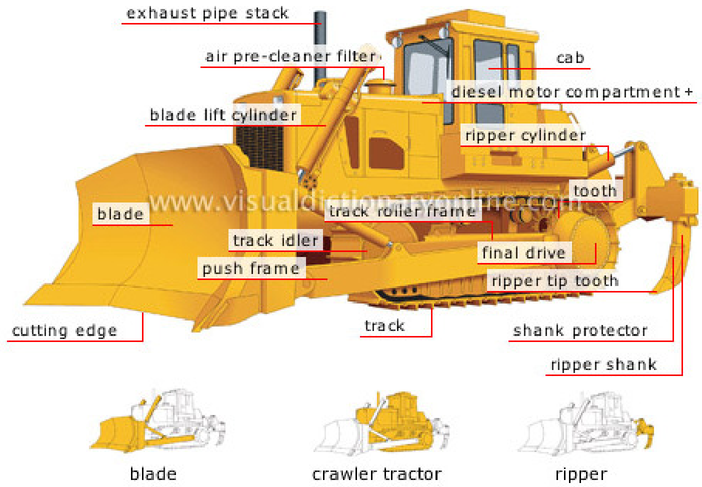


Figure 4: A typical crawler bulldozer and its parts
(Photo courtesy of Visual dictionary online)

Due to their size and weight, bulldozer accidents are extremely dangerous and life threatening for operators and especially for workers around them. Bulldozer accidents can include rollovers, run-over, and falls (Nunnally, 2000).

Sometimes with poor and limited visibility, uneven work surfaces make it easy for operators to come too close to a ledge or ditch and slide the equipment down the edge, causing rollover accidents. Also, blind spots are danger zones for workers in close proximity to bulldozers. Blind spots cause workers to be struck or run over by the equipment. When this happens, the bulldozer might roll, putting the operator in danger of becoming pinned or crushed under the massive weight of the machine as well as the rollover protective structure when a seat belt is not used during operation of equipment.

**1.1.2.3 Excavator Safety**

An excavator is an excavating equipment with tracks or wheels which consists of a hydraulic boom, a dipper arm, a hydraulic digger bucket and a cab on a 360-degree rotating platform (Figure 5). A vast array of attachments such as clamshells, log grapplers, lifting hooks etc. can be used in order to increase usefulness according to the type of work. Excavators are very commonly used in the construction industry as well as in other industries. They are used in a wide variety of tasks including but not limited to trench excavation, forestry work, general grading/landscaping, demolition, rigging, pile driving, and material handling.

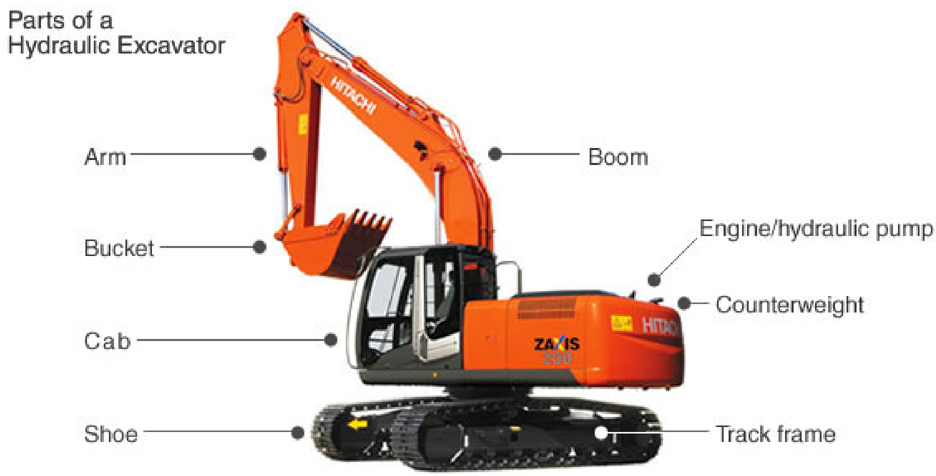


Figure 5: A typical track hydraulic excavator and its parts
(Photo courtesy of Nam-Kwang ST)

Their rotating ability and size cause danger to workers around them. Different than backhoes, excavators have two danger zones. The first danger zone is the swing radius of the boom and the dipper bucket; the second one is the radius of the rotating platform. Workers in these danger zones are commonly exposed to being struck by the bucket dipper arm or the rotating platform, caught in between a fixed structure or vehicle, or inadvertently struck by falling material. Excavators are also responsible for run-over accidents where the equipment is mobile even though they are not as mobile as a bulldozer or backhoe. On the other hand, operators are also in danger due to electrocution and being struck-by falling materials. They are also exposed to rollover accidents when the work is on uneven surfaces such as steep hills.

**1.1.2.4 Scraper Safety**

A scraper is a wheeled tractor with a hopper (bowl) attached behind it, and it is capable of loading, hauling and dumping vast quantities of earth at a relatively high speed (Alves et. al., 2003). It consists of a vertically moveable hydraulic hopper with a sharp horizontal front edge, a vertical blade (apron) which closes the hopper and lets the scraper haul material, a scraper ejector which is activated during dumping activity, and a pulling wheeled tractor which lets the scraper operate itself without the help of another push (Figure 6).

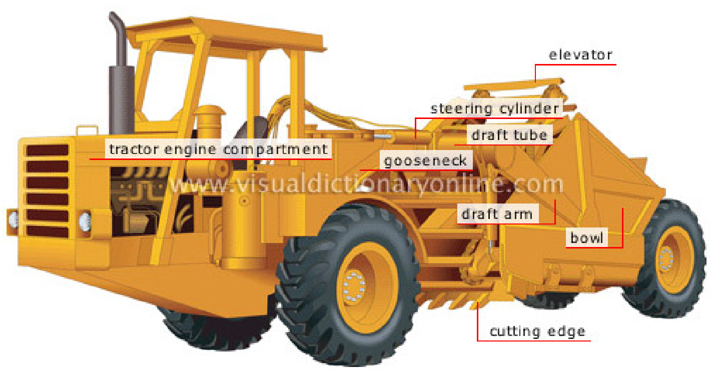


Figure 6: A typical scraper and its parts
(Photo courtesy of Visual dictionary online)

A scraper's high speed capability and size makes workers on the construction field vulnerable to struck-by accidents and caught in between accidents. Operators are also in danger of rollover accidents.

**Summary**

The construction industry in the U.S. is one of the leading industries in regard to work-related injuries and fatalities. Construction sites and heavy construction equipment in these sites create a unique potential for injury. In order to prevent and reduce heavy construction equipment related accidents, workers' safety awareness needs to be improved. To reduce heavy construction equipment related accidents, those who operate heavy construction equipment should possess the skill and experience to safely operate the equipment; also, on-foot workers should work safely when working in close proximity to these heavy construction equipment.

OSHA regulations dictate that all employers have a duty to protect their workers from injury and illnesses on the job and provide a safe working environment. Hence, it is employers' responsibility to train and educate workers for all potential life threatening hazards related to the job they perform as well as around them.

The remainder of this dissertation deals with the safety of earthmoving equipment, such as backhoes, scrapers, excavators and bulldozers.

### 1.2 Problem Statement

Heavy construction equipment accidents in general rank among the leading causes of work-related injuries and fatalities in the U.S. Often, the sheer size of the equipment itself makes the jobsite more dangerous. Victims of these accidents often suffer injuries that prevent them from returning to work.

While many construction activities have inherent hazards, the existence of heavy construction equipment on construction sites poses additional complexities since space is often limited and may be constrained by competing work crews, flow materials, movement of equipment and installation of temporary facilities and other structures (Sadeghpour and Teizer, 2009).Personnel on-foot and mobile heavy construction equipment often work in the same area, at the same time very closely. Unless heavy construction equipment operations are effectively managed, there can be serious safety problems. If vehicle safety practices are not observed at the work site, workers are exposed to the risk of being caught (pinned) between construction vehicles and walls, struck by swinging equipment attachments, crushed under overturned vehicles, or other similar accidents.

If proper precautions are taken and the factors involved in these accidents are better understood, heavy construction equipment accidents can be prevented. While the state and federal laws related to construction worker safety and labor groups have been diligently working to improve safety, a large portion of the construction workforce may not be strongly positioned to reduce work related injury and fatality risks. OSHA regulations covering heavy construction equipment are not specific enough to point out quality of training. At present, there isn't a dedicated OSHA standard specific to heavy construction equipment. Instead, OSHA covers different aspects for heavy construction equipment safety under different regulations, such as 29 CFR 1926.600, 29 CFR 1926.601, 29 CFR 1926.602, 29 CFR 1926.604, 29 CFR 1926.651(e), 29 CFR 1926.651(f).

Further, there are no federal or state statutes that currently require heavy construction equipment operators, except for crane operators, to be certified by a recognized body. Additionally, heavy construction equipment manufacturers publish safe operation procedures and appropriate warnings for each unit they manufacture. However, there is no enforcement on following these published procedures. In addition, training is left entirely up to the firm. Some firms with more stringent in-house safety policies may require that all of the operators be trained by an outside agency. Other firms may elect to have the person who has previously operated that equipment train the new employee with or without regard to their level of expertise and safety knowledge. Still others may attempt to operate the equipment with very little, if any training. Therefore, lack of this enforcement and certification puts on-foot workers as well as operators in jeopardy state.

In view of these considerations, research is needed to identify and understand the factors that contribute to accidents, especially understanding how and why they occur. The information and knowledge derived from this research could then be used to develop more effective accident prevention methods and strategies.

### 1.3 Research Objectives

The primary objectives of this study are as follows:

- To identify and review the factors that describe and classify heavy construction equipment related accidents
- To establish and gain insights into the relationships existing between these factors
- To distinguish between the characteristics of fatal and nonfatal accidents and predict the occurrence of fatal accidents
- To distinguish between accidents involving different worker and equipment categories
- To outline a statistical methodology for analyzing OSHA accident data to develop safety improvements ( based on quantified risk)

### 1.4 Research Approach

The research approach of this study incorporates three phases. The first phase is a state-of-the-art literature survey, which involves reviewing the existing information and knowledgebase regarding heavy construction equipment and heavy construction equipment-related accidents. The second phase is data acquisition and organization of the research data. For this phase OSHA accident records were used focusing on selected heavy equipment related accidents on construction sites. The data were coded and organized according to the variables that are introduced in the methodology section of this dissertation. Database programs such as Microsoft Access and Microsoft Excel were used as tools to organize the data. The third and final phase of the study was the univariate and multivariate statistical data analysis. Following the state-of-the-art review, the data and statistical analysis fundamentals are described in the methodology chapter and the results are presented and discussed in the ensuing chapter. In the last chapter, of this dissertation, a summary is presented, along with conclusions and recommendations.

.

# CHAPTER 2

## STATE – OF –THE – ART– REVIEW

This chapter presents a comprehensive literature review in order to gain a broad understanding of all aspects of safety for personnel who work with, near or around heavy construction equipment. This state-of-the-art (SOA) review helped the researcher to identify the hazards for personnel and applicable remedies for these hazards. Furthermore, this review was used to identify available heavy construction equipment related publications, covering previously identified hazards, suggestions by other researchers, advanced technologies adopted for heavy construction equipment related accidents, newly recommended safety procedures, shortcomings of existing remedies, best practices and preventative measures. The state-of-the-art review was conducted through web-based queries, as well as library searches to gather and interpret information available on heavy construction equipment safety. Searches were conducted in all relevant construction journals such as the Journal of Construction Engineering and Management, Journal of Safety Research and other published reports and documents from recognized sources. All identified papers and reports were critically reviewed in order to expand our knowledge and understanding of the factors about the causation and prevention of construction industry accidents.

This state-of-the-art review was conducted to identify what is known and not known about heavy construction equipment safety. Similar studies were included in the SOA review to capture the available information and how the data were organized and analyzed by other researchers. A comprehensive search was conducted including review of books, standards, published papers, articles, and dissertations pertaining to "construction safety and health" and "heavy construction equipment safety".

### 2.1 Construction Safety

Baradan (2004) reported in his dissertation that construction safety studies fall into 5 groups: accident statistics, causes of construction accidents, and accident costs; on site accident prevention methods; the role of stakeholders in preventing accidents; and legal, institutional and economic aspects of construction safety and health.

There are high numbers of published papers on construction safety; however, relatively few focus on heavy construction equipment accidents and related safety issues. Most published papers about heavy construction equipment focus on improving productivity rate and cost-benefit relations. Consequently, papers about construction accident analysis are included in this state-of-the-art review in order to learn how researchers have utilized statistical analyses: where they get their data from and how they used this data to reach their results and conclusions.

Hinze and Russell (1995) conducted a research study analyzing construction fatalities recorded by OSHA in the years 1980, 1985, and 1990. The study focused on the areas where the number of fatalities and violations were the greatest. It was emphasized that falls were one of the main causes of the fatalities (37%) followed by struck-by, struck against and caught in between accidents. It was indicated that heavy construction equipment played a tragic role in these fatalities. As a result, it was recommended that safety programs could be modified to more directly focus on these identified areas and OSHA should use an improved coding system to benefit more from acquired data associated with injuries and illnesses.

Culver et. al. (1990) studied the OSHA IMIS database for 1985-1989. They presented the results of a univariate analysis of the 3,496 construction fatalities investigated by the Occupational Safety and Health Administration for the indicated period. The analysis considered the variation in the number of fatalities over the 5-year period and the influence of factors such as geography and characteristics of the workforce, e.g., industry group, age, and union affiliation on these fatality statistics. The analysis also examined the causes of fatalities and the factors influencing accidents. The study showed that falls were the leading cause of fatality in construction accidents (33 percent), struck-by accidents were the second (22 percent), caught in between arrived as the third (18 percent), electrocution was the fourth cause (17 percent), and other causes came in fifth.

### 2.2 Heavy Construction Equipment Safety

Another study published by Hinze, Huang and Terry (2005) investigated the struck-by accidents by analyzing a total of 743 accident cases with data from 1997 through 2000, which were obtained directly from OSHA's IMIS database, in order to gain insights into the root causes of the struck-by injuries. In one of the authors previous study (Hinze, 1997) using data collected from 1980, 1985, and 1990, it was found that 70% of the struck-by accidents resulted from being struck by a falling object; struck by a crane, boom, or load; struck by a trench cave in; and workers being run over by heavy construction equipment or private vehicles. In the light of this information in order to identify the nature of the struck by accidents, authors used specific variables such as age, accident occurrence time, month of the year, material involved in the accident, equipment involved in the accident, human factors involved in the accident, and environmental factors involved in the accident in their study. They also investigated the frequency of equipment associated cases where struck-by material occurred. Their reasoning on using these variables was OSHA's coding system. Accident summaries in these reports contain this information. Furthermore, researchers utilized univariate analysis and the frequency distribution method on the data to facilitate a better understanding of struck- by accidents and presented findings by using bar charts.

It was found in this study that of the 497 cases identified as involving equipment, the most common types of equipment involving in struck – by incidents were related to trucks, private vehicles, cranes, backhoes, loaders, forklifts, bulldozers, hoists, rollers, saws, scrapers, and other type of equipment.

According to the author's analyses, accident occurrence was highest during March, April, the summer months, and October. The workers' age ranging from 30 to 39 was the highest percentage (27.6%) of injuries and fatalities. Results also showed that the materials most commonly striking a victim were wood assemblies (walls, trusses, and formwork) and soil/rock. Further analysis of this matter showed that cranes, trucks, and backhoes were the equipment types most frequently involved in accidents where the employee was struck by some type of material. The main human factor was identified as misjudgment of hazardous situation by 35.8 percent, where as other human factors listed had frequencies below 10 percent. In conclusion, authors suggested that accident prevention programs should focus on the major types of equipment, and material involved in struck-by accidents; extensive planning of the site layout should be conducted to minimize material movement over employees. They also indicated that improved safety training of employees was needed to insure accident-free construction sites.

A recent study conducted by McCann (2006) focused on heavy construction equipment and truck-related deaths on excavation work sites. The heavy construction equipment in this study included bulldozers, backhoes, and other excavating equipment, as well as other mobile construction equipment. Trucks included dump trucks, semitrailers, and tractor trailers. The investigation involved 38 NIOSH Fatality Assessment and Control Evaluation (FACE) reports about excavation deaths in construction involving heavy construction equipment and trucks. McCann found that 20 accident cases involved the deaths of workers on-foot and 18 involved the deaths of equipment operators. Furthermore, out of the 20 worker-on-foot deaths, 5 of 7 were struck by vehicles when they were backing up, and 9 deaths involved workers struck by vehicle parts (e.g., backhoe buckets) or vehicle loads. Of the nine operator deaths due to vehicle rollovers, three involved seat belts not fastened, one had the seat belt removed, and one seat belt malfunctioned. Six operator deaths occurred while they were maintaining their vehicle. Five involved failure to set brakes or otherwise lock out the vehicle while working on it.

Mccann mentions that since the NIOSH FACE reports investigate only selected deaths, the results are not specifically indicative of the actual breakdown of causes of death. Later, in the same paper, the author took up the construction industry fatality data for the 2-digit BLS Standardized Industrial Classification (SIC) Codes 15, 16, and 17 for the 11-year period from 1992 to 2002 in the Census of Fatal Occupational Injuries (CFOI) database. The author filtered out the excavation work related data from the whole dataset by using the SIC code (1794 excavation work) in records. McCann managed to gather 481 records which only cover excavation work. By relying primarily on the narratives for each case, a total of 253 heavy equipment- and truck-related deaths on construction sites were identified by the author. The author classified workers killed into the following categories based on where they were killed: vehicle operator, worker on-foot, worker maintaining vehicle, and other based on narratives of CFOI record. Again, based on narratives and the event code, he classified the causes of death into the following categories: rollovers, struck-by vehicle, struck-by object, caught in/between, and others. The author, by using frequency distribution analyses method, tabulated his findings on the causes of construction site heavy construction equipment and truck-related deaths with the types of vehicles involved

McCann noted that 41% of the backhoe accident deaths involved workers who were struck by objects, including backhoe booms and buckets, backhoe loads, and falling backhoes. The author also underlined that one of the main causes of deaths of operators on-foot and of workers maintaining vehicles was failure to set brakes, leaving vehicles in gear or other failures to lock out vehicles when getting off them or working around them. He suggested promulgation of an OSHA lockout/tagout standard for construction. According to these findings the author also mentioned that for workers on-foot, being struck by vehicles, especially backing vehicles, and being struck by vehicle loads and vehicle parts were the major causes of death. For workers in trenches, being struck by backhoe loads and backhoe parts or falling backhoes caused three-quarters of the deaths. Author's recommendations included establishing restricted access zones, requiring spotters for workers who have to be near heavy equipment, and the development of effective warnings systems for operators of backing vehicles.

Hinze, Pedersen, and Fredley (1998) examined the concept of accident prevention by suggesting that it begins with having a clear understanding of those factors that play key roles in their causation. One source of information on causes associated with many serious injuries and fatalities is maintained by the Occupational Safety and Health Administration (OSHA). This information is contained in abstracts that are brief descriptions of the conditions and circumstances that were existent at the time of the accidents. At the time the Hinze et al. paper was written, unlike today, the authors pointed out that the information could not be retrieved readily. They also made some suggestions regarding how the OSHA reports could be made more meaningful. They concluded that information could be utilized to focus greater attention on those areas for which modifications in the regulations were warranted, and it would be more helpful to the construction industry by emphasizing the major causes of serious accidents.

# CHAPTER 3

# METHODOLOGY

## 3.1 Data Source, Data Acquisition and Data Validation

This section describes the data source and data acquisition methodology. In addition to these, information regarding validation is given in this section. Figure 7 displays the logic diagram that was followed for data acquisition and organization.

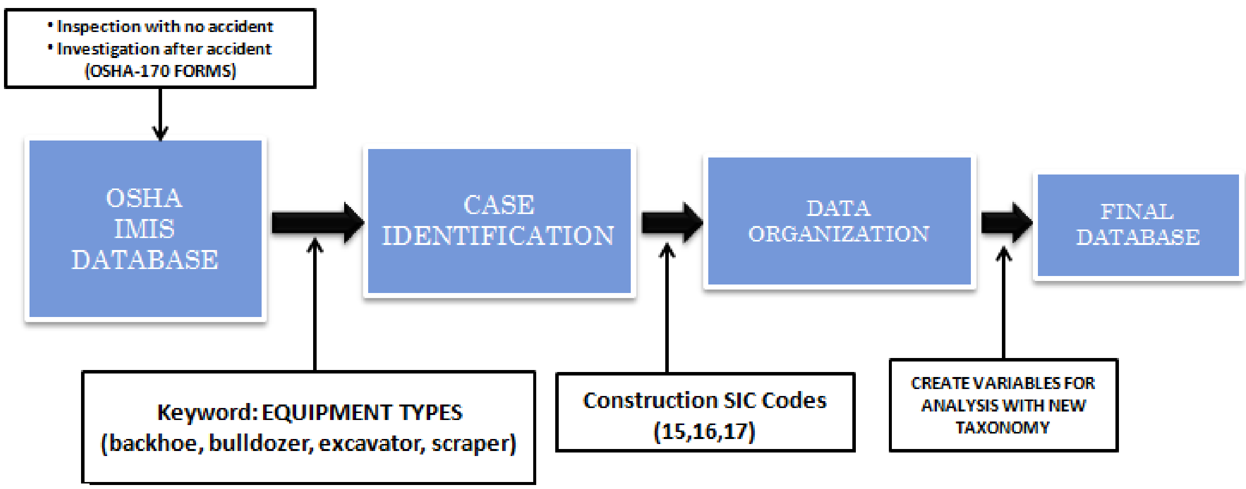


Figure 7: Data Acquisition Logic Diagram

Data used in this research were acquired from occupational accident reports. Data from such accident reports have been commonly used in construction safety studies in the U.S. as well as in other countries by various researchers (Hatipkarasulu, 2010; McCann, 2006; Hinze and Teizer, 2011; Hinze et. al., 2005; Pratt et.al., 1997) to shed light on different types of accidents in the US construction industry. In this study, data was acquired from the OSHA Integrated Management Information System (IMIS) database which is publicly accessible on the OSHA website. The IMIS database hosts accident investigation reports which are documented on OSHA-170 - Investigation Summary forms that result from OSHA accident investigations. OSHA compliance officers follow the guidelines in the “Field Operations Manual” (http://www.osha.gov/OshDoc/Directive_pdf/CPL_02-00-148.pdf) published by OSHA to conduct accident investigations and fill out the OSHA-170 form.

OSHA, by law, investigates all cases that result in fatalities from a work-related accident or any accident that involves inpatient hospitalization of three or more employees. An establishment also has to report each fatal injury or multiple hospitalization accident within thirty (30) days of occurrence. It is important to mention that fatalities resulting from personal illness or some other non safety-related cause are not usually subject to routine OSHA investigations. Furthermore, State-Plan states (26 states that operate OSHA-approved State Plans e.g. CalOSHA, MIOSHA, WISHA) may define catastrophic accidents differently for their investigations. However, all accident investigations in the 50 states, Puerto Rico, the Virgin Islands and the District of Columbia are supposed to be included in the IMIS database.

Occupational accident reports (OSHA-170) in OSHA’s IMIS database used to record a summary of all events relating to the fatality/catastrophe, and they are very rich with raw information. They provide information on the incident date, the establishment name, Standard Industrial Classification (SIC), an abstract of the accident occurrence, information about the project (end use, type, cost, location), citation information if given (type of citation, cited standard, abatement status, amount of penalty assigned), information about the injured worker (age, sex, union status, task assignment, degree of injury, part of body, occupation), and additional information about accident in terms of environmental factors, human factors, event type, the nature of the injury, fall height and so on. A sample accident investigation report is placed in Appendix A. It should be noted that citations mentioned in these reports are finalized decisions. If an establishment appeals a citation, this case is forwarded to OSHRC (Occupational Safety & Health Review Commission), and this agency reviews this appeal and decides whether to contest the citations or penalties resulting from OSHA investigations and inspections. If OSHRC decides in favor of the appealing establishment, citations are deleted, and these deletions are marked as “deleted” right next to the citation in the IMIS accident reports.

As illustrated in Figure 3, the first step was to identify relevant cases for the study. Thus, heavy construction equipment related cases were drawn from the OSHA IMIS database by using the OSHA Accident Investigation webpage’s search engine under the data and statistics section (http://www.osha.gov/pls/imis/accidentsearch.html). Specific earthmoving equipment names (backhoe, bulldozer, scraper and excavator) were used as keywords to filter the cases. These equipment types are the ones adopted for inclusion in our research scope. Accident summary numbers were recorded in a Microsoft Excel file so that detailed information could be requested from OSHA.

By using the Freedom of Information Act (FOIA), a formal data request letter was faxed to the main OSHA office in Washington along with the identified case summary numbers. As a result, OSHA provided a total of 1518 accident reports pertaining accidents related to backhoes (710), excavators (275), bulldozers (385), and scrapers (148) occurring during the time period between 1982 through 2008.

Since a general search, regardless of the industry, was conducted to identify the cases, the second step was to identify the accidents specifically related to the construction industry. The reason behind this step was to keep the study focused on the construction industry only in order to meet the objectives of the research. Hence, cases recorded for other industries such as mining, farming, agricultural, manufacturing, wholesale trading were eliminated from the OSHA provided dataset. To do so, cases from other industries were eliminated by applying the filtering system using MS Excel. Standard Industrial Classification code (SIC) and accident case summaries were the supporting tools to identify these cases. All cases constituting the final dataset used for this research are classified under SIC division C construction, and include the following major groups and subgroups:

- Major Group 15: Building construction general contractors and operative builders
  - **Industry Group 152: General Building Contractors-residential**
    - 1521 General Contractors-Single-Family Houses
    - 1522 General Contractors-Residential Buildings, Other Than Single-Family
  - **Industry Group 153: Operative Builders**
    - 1531 Operative Builders
  - **Industry Group 154: General Building Contractors-nonresidential**
    - 1541 General Contractors-Industrial Buildings and Warehouses
    - 1542 General Contractors-Nonresidential Buildings, Other than Industrial Buildings and Warehouses
- Major Group 16: Heavy construction other than building construction contractors
  - **Industry Group 161: Highway And Street Construction, Except**
    - 1611 Highway and Street Construction, Except Elevated Highways

- **Industry Group 162: Heavy Construction, Except Highway And Street**
  - 1622 Bridge, Tunnel, and Elevated Highway Construction
  - 1623 Water, Sewer, Pipeline, and Communications and Power Line Construction
  - 1629 Heavy Construction, Not Elsewhere Classified

- Major Group 17: Construction special trade contractors
  - **Industry Group 171: Plumbing, Heating And Air-conditioning**
    - 1711 Plumbing, Heating and Air-Conditioning
  - **Industry Group 172: Painting And Paper Hanging**
    - 1721 Painting and Paper Hanging
  - **Industry Group 173: Electrical Work**
    - 1731 Electrical Work
  - **Industry Group 174: Masonry, Stonework, Tile Setting, And Plastering**
    - 1741 Masonry, Stone Setting, and Other Stone Work
    - 1742 Plastering, Drywall, Acoustical, and Insulation Work
    - 1743 Terrazzo, Tile, Marble, and Mosaic Work
  - **Industry Group 175: Carpentry And Floor Work**
    - 1751 Carpentry Work
    - 1752 Floor Laying and Other Floor Work, Not Elsewhere Classified
  - **Industry Group 176: Roofing, Siding, And Sheet Metal Work**
    - 1761 Roofing, Siding, and Sheet Metal Work
  - **Industry Group 177: Concrete Work**
    - 1771 Concrete Work

- **Industry Group 178: Water Well Drilling**
  - 1781 Water Well Drilling
- **Industry Group 179: Miscellaneous Special Trade Contractors**
  - 1791 Structural Steel Erection
  - 1793 Glass and Glazing Work
  - 1794 Excavation Work
  - 1795 Wrecking and Demolition Work
  - 1796 Installation or Erection of Building Equipment, Not Elsewhere
  - 1799 Special Trade Contractors, Not Elsewhere Classified

Finally, after the second step filtration of the cases (1065 accident reports) 507 cases for backhoe, 227 cases for bulldozer, 224 cases for excavator and 107 cases for scraper were selected for this research, covering the years 1983 through 2008.

For data validation, the data source (OSHA) relies on various methods for validating and verifying data used in performance measurement, such as comparison with previous data from the IMIS, comparison with another reliable source of the same type of data within OSHA (IMIS and OCIS) and edits contained within IMIS.A detailed explanation of data validation and quality assurance methods are explained by OSHA in its strategic plan publication (OSHA, 1998). Data validation part of this publication is presented in Appendix B.

The final database was designed and developed in MS Excel and initially prepared by organizing the cases using the original OSHA taxonomy (Table 3). Subsequently, a new taxonomy for the research database was established for performing the statistical analysis needed for this research. Explanations are provided under the Data Organization section, which follows.

## 3.2 Data Organization

### 3.2.1 Variables

As shown in Figure 8, research variables incorporated in statistical analysis were chosen from the already existing OSHA taxonomy, as well as from a newly created taxonomy. A total of 26 variables were used in this study; twelve of these variables were associated with the original OSHA taxonomy although some of them were modified in order to reduce the number of levels. The other remaining variables (14) were newly created by using citations and investigation report abstracts.

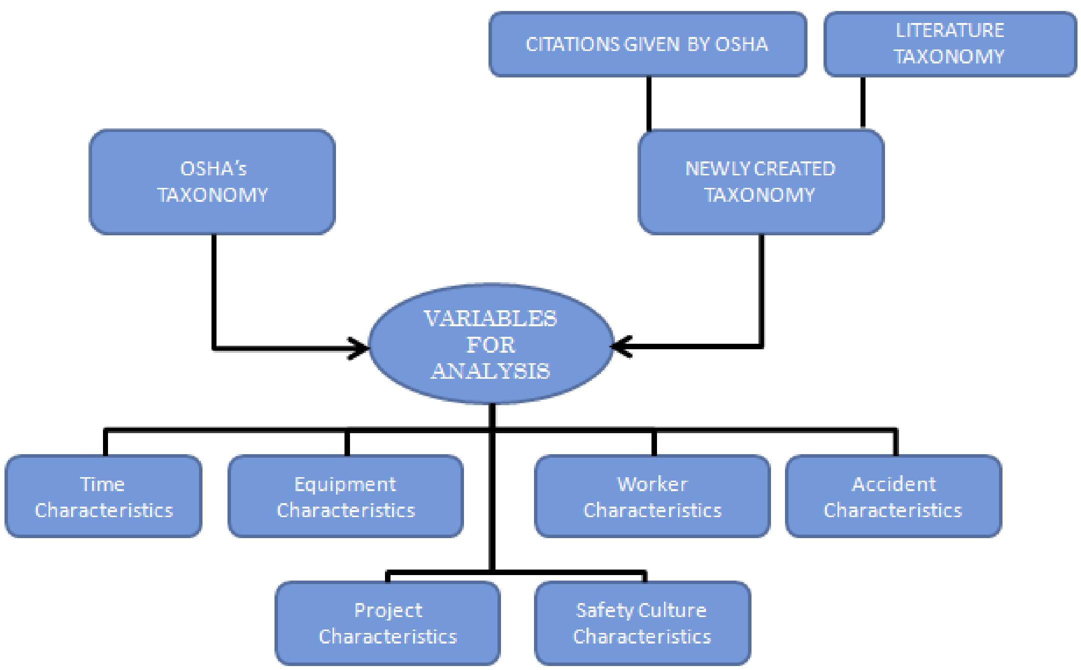


Figure 8: Research variable creation and organization logic diagram

Final research variables were grouped under six different headings according to their relevance to their characteristics. These headings are time characteristics, project characteristics, and equipment characteristics, worker characteristics, accident characteristics, safety culture characteristics. They are briefly described below.

**Time Characteristics Variables**: This group was organized according to the accident occurrence date and included days of the week and months of the year.

**Project Characteristics Variables**: These variables give information about the progressing project when accident occurred. Construction sites are unique dynamic environments; they are different in shape and size. These variables help to classify and understand the construction environment where accidents mostly occur,

**Equipment Characteristics Variables**: It is crucial to understand the characteristics of heavy construction equipment that are involved in accidents in order to analyze possible contributing factors in these accidents. Written brief abstracts or summaries of what happened during accidents, which are documented by the OSHA compliance officers upon completion of the accident investigation were used to identify these characteristics.

**Accident Characteristics Variables**: Variables in this group give plenty of information regarding the accident; in other words, they define the accident.

**Worker Characteristics Variables**: As one can easily understand, variables explaining the victim’s information were listed under this group.

**Safety Culture Characteristics Variables**: Company safety culture information giving variables were gathered under this group.

The following sections describe these variables and their values, and how they were finalized and entered into the statistical analysis.

**3.2.1.1 OSHA's taxonomy**

Information presented in Table 3 comes from OSHA's original taxonomy. The variables can be categorized as continuous, nominal, and ordinal. As a starting point for developing and organizing the final research database, each variable and its assigned values were entered into an MS Excel sheet as a categorical variable with the original OSHA taxonomy. This raw dataset was entered into the SPSS software, and a first pass of univariate analysis was conducted. The main purpose of this step was to identify how cases were distributed among the levels of each variable. As expected, frequencies for those variables with more than 5 levels produced small numbers. Low frequency numbers in categorical variable levels makes it difficult to interpret the results for crosstabulation analysis and binary logistic regression analysis as well as univariate analysis. Thus, an attempt was made in the early stages of this study to reduce the number of categorical variable levels by using data refinement methodology in order to ease the interpretation of the analysis results. This approach is commonly implemented by other researchers doing similar work (Al-Ghamdi, 2002; Hatipkarasulu, 2010).

Table 3: Variables from original OSHA taxonomy and their category values

| VARIABLE | LEVEL VALUES |
|---|---|
| Day | Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday |
| Month | Jan., Feb., March, April, May, June, July, Aug., Sept., Oct., Nov., Dec. |
| Year | 1983-2008 |
| Gender | Male; Female |

| VARIABLE | LEVEL VALUES |
|---|---|
| SIC code | 1623,1794,1629,1611,1542,1711,1622,1521,1771,1799,1795,1731,1541,1522<br><br>1522,1741,1791,1781,1531,1751,1742 |
| Project Type | PTYP-A New project or new addition<br>PTYP-B Alteration or rehabilitation<br>PTYP-C Maintenance or repair<br>PTYP-D Demolition<br>PTYP-E Other |
| Project End use | ENDU-A Single family or duplex dwelling<br>ENDU-B Multi-family dwelling<br>ENDU-C Commercial building<br>ENDU-D Manufacturing plant<br>ENDU-E Refinery<br>ENDU-F Power plant<br>ENDU-G Sewer/water treatment plant<br>ENDU-H Other building<br>ENDU-I Highway, road, street<br>ENDU-J Bridge<br>ENDU-K Tower, tank, storage ,elevator<br>ENDU-L Shoreline development, dam, reservoir<br>ENDU-M Pipeline<br>ENDU-N Excavation, landfill<br>ENDU-O Power line, transmission line<br>ENDU-P Other heavy construction<br>ENDU-Q Contractor's yard/facility |
| Event Type | 01 Struck-by<br>02 Caught in or between<br>03 Bite/sting/scratch<br>04 Fall (same level)<br>05 Fall (from elevation)<br>06 Struck against<br>07 Rubbed/abraded<br>08 Inhalation<br>09 Ingestion<br>10 Absorption<br>11 Rep. Motion/pressure<br>12 Card-vascular/resp. fail.<br>13 Shock<br>14 Other |
| Degree of Injury | Fatal<br><br>Nonfatal |
| Age | 16-75 |
| Union Status | Union; Non Union |
| Task Assignment | Regularly assigned<br><br>Not regularly assigned |

| VARIABLE | LEVEL VALUES | |
|---|---|---|
| Environmental factor | 01 | Pinch Point Action |
| | 02 | Catch Point/Puncture Action |
| | 03 | Shear Point Action |
| | 04 | Squeeze Point Action |
| | 05 | Flying Object Action |
| | 06 | Overhead Moving/Falling Object Action |
| | 07 | Gas/Vapor/Mist/Fume/Smoke/Dust |
| | 08 | Materials Handling Equip./Method |
| | 09 | Chemical Action/Reaction Expos |
| | 10 | Flammable Liquid/Solid Exposure |
| | 11 | Temperature +/- Tolerance Lev. |
| | 12 | Radiation Condition |
| | 13 | Work-Surface/Facility-Layout Condition |
| | 14 | Illumination |
| | 15 | Overpressure/Underpressure |
| | 16 | Sound Level |
| | 17 | Weather, Earthquake, Etc. |
| | 18 | Other |
| Human factor | 01 | Misjudgment, Hazardous Situation |
| | 02 | No Personal Protective Equipment Used |
| | 03 | No Appropriate  Protective Clothing |
| | 04 | Malfunction In Securing/Warning Op |
| | 05 | Distracting Actions By Others |
| | 06 | Equipment Inappropriate For Operation |
| | 07 | Malfunction Neuromuscular System |
| | 08 | Perception Malfunction Task-Environment |
| | 09 | Safety Devices Removed/Inoperable |
| | 10 | Position Inappropriate For Task |
| | 11 | Mater-Handling Procedure Inappropriate |
| | 12 | Defective Equipment In Use |
| | 13 | Lockout/Tagout Procedure Malfunction |
| | 14 | Other |
| | 15 | Insufficient/Lack/Housekeeping Program |
| | 16 | Insufficient /Lack/Expose/Biological Monitoring. |
| | 17 | Insufficient /Lack/Engineering Controls |
| | 18 | Insufficient /Lack/Written Work Practice Program |
| | 19 | Insufficient /Lack/Respiratory Protection |
| | 20 | Insufficient /Lack/Protective Work Clothing/Equipment |

As seen in Table 3, due to their large number of levels, the variables “project end use, event type, environmental factor, human factor, age and SIC code” showed very low frequency counts in some category levels. Therefore, a secondary effort was conducted to reduce the category levels of these variables.

Hatipkarasulu (2010) suggests combining some of the project end use category levels under new names. By adopting his technique and suggestion, 17 level project end use variables were reduced to 6 levels by merging some of the statistically independent levels. Final project end use variable levels are as follows;

- Residential (Single family or duplex dwelling, Multi-family dwelling )
- Commercial (Commercial building, Contractor's yard/facility)
- Industrial (Manufacturing plant, Refinery, Powerplant, Sewer/water treatment plant,
- Other building (Other building)
- Highway (Highway, road, street)
- Heavy/Civil (Bridge, tower, tank, storage elevator, shoreline development, dam, reservoir, pipeline, excavation, landfill, powerline, transmission line, other heavy construction)

The “event type” variable had 14 levels; after merging some levels together this number was reduced to 5. The finalized event type variable level values became the following:

- Struck-by (struck-by; struck against)
- Caught In or between
- Electrocution ( Shock)
- Fall ( Fall from elevation, fall on the same level)

- Other (Bite/sting/scratch, ingestion, inhalation, cardio-vascular/respiratory failure, absorption repetitive motion / pressure, rubbed /abraded,other)

The 18-level “environmental factor” variable was reduced to 10-levels, including a new level “blind spot” which was identified by reading the case abstracts. This was originally coded under “other” by OSHA. As mentioned in the literature review blind spots are one of the major concerns when heavy construction equipment are involved in accidents. Final category levels of this variable are listed below:

- Materials handling equipment/method
- Work-surface/facility layout condition
- Overhead moving/falling object action
- Squeeze point action
- Pinch point action
- Flying object action
- Flammable liquid/solid exposure
- Catch point/puncture action
- Blind spot
- Other

There were 20 levels listed under the “human factor” variable; this number was reduced to 7 by merging statistically independent levels. The new levels were as follows:

- Misjudgment of hazardous situation
- Inappropriate choice/use of equipment/methods
- Inoperable/malfunctioned safety/warning devices
- Insufficient engineering and admin controls

- Human system malfunction
- Distracting actions by others
- Other

For “age”, a continuous variable, it was decided to form a categorical variable that could be easily interpreted and used in crosstabulation analysis. Age levels were adopted by previous researchers’ work; a study conducted by Hinze, Huang and Terry (2005) use the following category, and their age categorization was adopted directly so that each victim’s age was assigned to the appropriate level. These level values are as follows;

- <20
- 20-24
- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- >64

The SIC code had 20 different levels. As a result of a secondary analysis, it was decided to reduce this number to 5 by merging some low count levels together. The final level values for SIC variable are as follows:

- 1623 - Water, Sewer, Pipeline, and Communications and Power Line Construction
- 1794 - Excavation Work
- 1629 - Heavy Construction, Not Elsewhere Classified
- 1611- Highway and Street Construction, Except Elevated Highways

- All Others (1521, 1522, 1531, 1541, 1542, 1622, 1711, 1731, 1741, 1742, 1751, 1771, 1781, 1791, 1795, 1799)

#### 3.2.1.2 Newly Created Taxonomy

Twelve newly created variables were used in this study to shed additional light on heavy construction equipment related accidents. All these new variables were created by reading the abstracts and using the supporting information provided by OSHA investigation reports posted on OSHA website. These newly created variables were chosen from the previous research findings and suggestions. For example, almost all of the construction safety related literature suggests that safety training should be given to workers to increase their hazard recognition ability and mastery of the safe work practices. Therefore, citations issued to establishments due to violation of safety training regulations (Subpart C- 1926.21) helped us to identify safety training for inclusion in our study. It was revealed in our state-of-the-art review that citations issued by OSHA are only studied by only a few researchers to identify the most commonly cited standards.

The new variables and their category levels are introduced in this section.

**Equipment Type:** This variable shows the type of equipment involved in the accident. By using the keywords in accident reports, specific equipment types were identified for the cases. This variable has 4 levels, which are:

- Backhoe
- Bulldozer
- Excavator
- Scraper

**Equipment Part Involvement:** By reading the abstracts of accident reports, it was determined what part of the equipment was involved in the accident, directly or indirectly. This variable helps us identify event types in detail, such as struck by equipment, struck by attachment, and struck by flying object. To do so, three levels were assigned to this variable.

- Equipment's super structure (tracks, body, tires) involved in the accident.
- Equipment attachment involved: e.g. blades, arms, moving parts
- Carried/pushed load involved: The equipment are sometimes used for hosting/rigging and moving materials, this variable is created to identify if these loads were involved in the accident.

**Back-up Motion**: At the time of accident if the equipment was in back-up motion then a 'yes" value was assigned; if not, it was marked as "no".

**Roll-over Protection Structure (ROPS):** If involved equipment was equipped with a Roll-over Protection Structure (ROPS), it was assigned a "yes" value; if not, a "no" value was given.

**Seat Belt:** This variable questions whether a seat belt is installed on the equipment involved in the accident. OSHA regulations CFR 29 1926.601(b)(9) and 29 CFR 1926.602(a)(2)(i) were used to examine this variable. It is a nominal variable; presence is marked as "yes"; otherwise, it is checked as "no".

**Back-up Alarm:** Similar to the previous two variables, it inquires whether a back-up alarm was installed and in operating condition on the equipment to alert the workers while the involved equipment moved in the reverse direction. Presence was marked as "yes", absence or inoperable condition was marked as a "no". CFR 29 1926.601(b)(3) and CFR 29 1926.601(b) (4)(i) were used to identify the presence and operable condition or absence.

**Activity Prompting Accident:** In order to understand the activities prompting accident we developed the levels below by reading and analyzing the accident abstracts. Each case was assigned to an appropriate level where it fits best.

- Backfilling and compacting
- Site grading and rock removal
- Lifting/rigging
- Site clearing and grubbing
- Loading/Unloading material/equipment
- Pipe installation/trench excavation
- Riding equipment/on equipment
- Equipment maintenance
- Demolition
- Excavation other than trench

**Occupational Function**: This variable in the new taxonomy was created to indicate the victim's occupation. The accident abstracts were used to identify the occupation of the victims. They were categorized into two groups: workers who were operating the equipment, classified as "operator", and workers who were not involved in operating the equipment classified as "on-foot worker". It should be noted that if a worker was actually an operator, but at the time of the accident, he/she was not operating the equipment or on the equipment involved in an accident, these workers were classified as "on-foot worker".

**Safety Program:** OSHA citations were used to create this variable. OSHA regulation 29 CFR 1926.20 (b)(1) requires every company to have a safety (accident prevention) program. If OSHA gave a citation to the establishment due to not having such a program or noncompliance with the mentioned standard, it is marked as “not present”. If no citation was given, it was assigned a “present” value. At this point, the researcher is not sure how an OSHA compliance officer decides this citation. There are industry standards (ANSI) on safety programs; however, none are by OSHA other than model programs on the web. Therefore, the researcher assumes that OSHA compliance officers have a reasonably consistent way of deciding on citations regarding this aspect. Safety programs are complex due to their multi-faceted and variable nature. This complexity is more straight forward for safety training.

**Safety Training:** Similar to the safety program variable, this variable was also created with the help of OSHA citations. If OSHA gave a citation due to not providing evidence of training for the worker according to OSHA regulations, 29 CFR 1926.21(b)(2) and 29 CFR 1926.20(b)(4), the case was assigned to the appropriate category. It should also be noted that if a citation was deleted due to an appeal and OSHRC decided in favor of the appealing establishment, these cases were handled as if they had not been cited.

**Worker Protective System Usage (e.g. PPE, seat belt):** This variable indicates whether protective measures on workers had been used at the time of the accident.

**Equipment Protective Systems (e.g. brakes, bars, glass, horns):** This variable indicates if the equipment has proper protective systems, such as brakes, horns, seat belts, ROPS, installed and in working condition.

**Maintenance Issue:** This variable indicates whether lack of equipment itself or attachments, as well as protective systems inspection or maintenance, were a factor in the accident's occurrence.

The next section covers the final research variables, their levels and values, and how they are coded and entered into the statistical software.

### 3.3 Data Coding and Entry

After completing the refinement of the variables and their levels, the final dataset was entered into the SPSS software. Table 4 presents the six main characteristics described previously and the categorical variables grouped under these characteristics with their levels. Also, some variables are associated with only certain occupational function group such as seat belt concerns only equipment operators. Thus, these variables were identified with an asterisk and the definition of asterisk is given under the table.

Table 4: Final research variables and their levels

| VARIABLE | CATEGORY VALUES |
|---|---|
| **Time Characteristics** | |
| **Day** | Monday Thursday Sunday<br>Tuesday Friday<br>Wednesday Saturday |
| **Month** | Jan. May Sept.<br>Feb. June Oct.<br>March July Nov.<br>April Aug. Dec. |
| **Year** | 1983-2008 |

| Project Characteristics | |
|---|---|
| **Project Type** | New project or new addition<br>Alteration or rehabilitation<br>Maintenance or repair<br>Demolition<br>Other |
| **Project End use** | Residential<br>Commercial<br>Industrial<br>Other building<br>Highway<br>Heavy/Civil |
| **Equipment Characteristics** | |
| **Equipment Type** | Backhoe<br>Bulldozer<br>Excavator<br>Scraper |
| **Equipment Part Involvement** | Equipment super structure involved<br>Equipment Attachment Involved<br>Carried/Pushed Load Involved |
| **Back-up Motion Presence**** | Present<br>Not Present |
| **ROPS Presence*** | Present<br>Not Present |
| **Seat Belt Presence*** | Present<br>Not Present |
| **Back-up Alarm Presence/Cond.**** | Working<br>Not Working |
| **Worker Characteristics** | |
| **SIC code** | 1794<br>1629<br>1611<br>All Others |

* Concerns Operator only
** Concerns On-foot worker only

| | |
|---|---|
| **Union Status** | Union<br>Non-Union |
| **Gender** | Male<br>Female |
| **Task Assignment** | Regularly assigned<br>Not regularly assigned |
| **Occupational Function** | On-foot worker<br>Operator |
| **Age** | <20 45-49<br>20-24 50-54<br>25-29 55-59<br>30-34 60-64<br>35-39 >64<br>40-44 |
| **Accident Characteristics** | |
| **Degree of injury** | Fatal<br>Nonfatal |
| **Event Type** | Struck-by<br>Caught In or between<br>Electrocution<br>Fall<br>Other |
| **Environmental factor** | Materials handling equipment/method<br>Work-surface/facility layout condition<br>Overhead moving/falling object action<br>Squeeze point action<br>Pinch point action<br>Flying object action<br>Flammable liquid/solid exposure<br>Catch point / puncture action<br>Blind spot<br>Other |

| | |
|---|---|
| **Human factor** | Misjudgment of hazardous situation<br>Inappropriate choice/use of equipment/methods<br>Inoperable/malfunctioned safety/warning devices<br>Insufficient engineering and admin controls<br>Human system malfunction<br>Distracting actions by others<br>Other |
| **Activity Prompting Accident** | Backfilling and compacting<br>Site grading and rock removal<br>Lifting/rigging<br>Site clearing and grubbing<br>Loading/unloading material/equipment<br>Pipe installation/trench excavation<br>Riding equipment/on equipment<br>Equipment maintenance<br>Demolition<br>Excavation other than trench |
| **Safety Culture Characteristics** | |
| **Safety Program** | Present<br>Not present |
| **Safety Training** | Provided<br>Not provided |
| **Worker Protective System Usage (e.g. PPE, seat belt)** | Used<br>Not used |
| **Equipment Protective Systems (e.g brakes, bars, glass)** | Present<br>Not present |
| **Maintenance Issue** | Present<br>Not present |

### 3.4 Data Analysis

In this study data analyses relied on univariate analysis for data overview and classification, and crosstabulation and binary logistic regression analyses were performed to examine the relationships between the variables. In addition, we aimed to quantify the odds for independent variables that increase or decrease the dependent variable outcome. The statistical data analysis was conducted by using MS Excel and Statistical Package for Social Sciences (SPSS) software.

### 3.4.1 Univariate Analysis

Univariate analysis is the simplest form of statistical analysis which involves describing a case in terms of a single variable; specifically, the distribution of the levels that compose it (Babbie, 2010). Babbie in his book also mentions that the primary purpose of univariate analysis is descriptive; where as multivariate analysis is geared more towards explanatory purposes. In other words, it explains data and tells the researcher what he/she has in hand.

Univariate analysis has been the foundation of a researcher's data analysis for decades in many different science fields. This commonality and popularity also appears among construction safety researchers. In the vast majority of the construction safety literature, the findings are based on univariate analysis and aimed at shedding light on problematic areas in this field, especially accident causation (Hatipkarasulu 2010, Hinze et.al 1998, Hinze et. al 2005, etc). This popularity is because of not only its simplicity but also due to its help to explore and understand the data as well as guide researchers towards advanced data analysis. Unfortunately, not many advanced data analyses have been conducted in the construction safety field. Moreover, when the construction safety topic was narrowed down to heavy construction equipment related studies during the literature survey; no literature was identified as utilizing advance statistical data analysis methods other than univariate analysis.

In this research, univariate analysis was adopted for frequency analysis in two parts. The first part is for data screening purposes, and the second part is to understand what we have and choose the right variables for explanatory data analysis.

The most common way of presenting the univariate analysis findings are through bar charts, histograms, pie charts and frequency tables; we utilized bar charts and frequency tables for reporting purposes.

**3.4.1.1 Univariate Analysis for Screening Data Prior To Analysis**

As indicated in the previously presented Tables 3 and 4, the vast majority (99%) of the variables used in this research study are categorical variables with a different number of levels. Only one variable, 'age", was continuous; however, by adopting previous researchers' methodology, this variable was also converted into a categorical variable by assigning different ranges.

Univariate analysis for screening the data was conducted on the research dataset that includes all the variables without making any modifications. The aim was to answer the research questions given below.

Q-1 How many different levels does each variable have and what are their values?

Q-2 How many cases are there for each single level?

Q-3 Is there any missing data in the data set?

When the above three questions were answered, five variables; SIC code, project end use, event type, environmental factor, and human factor, have more than 10 levels. There are two problems underlying this high category number. The first problem is the broad observation count distribution, and the second one is the difficulty of interpreting the results during further data analysis (crosstabulation and logistic regression). If there are too many levels with small observation counts, it might be very difficult for a researcher to see any meaningful pattern. Kass (1980) suggests merging some levels in order to reach a meaningful conclusion. In statistics, this application is called “collapsing levels’. It is very common in statistical science and has also been applied to different types of studies. However, if the proper methods are not followed, an unimportant category may become very important due to merging with some other unimportant category, and its increasing frequency may mislead the researcher to interpret the result incorrectly. Therefore, the collapsing levels technique was applied to those with a high number of levels but low number of observation counts. SIC code, project end use, event type, environmental factor and human factor had reduction on level numbers, which is presented in Table 4.

Missing cases were also identified during the data screening process. Tabachnik and Fidell (2007) point out the importance of the pattern of missing data in a dataset. Our dataset had only three problematic variables in terms of missing data: project type, project end use and age. Project type and project end use information were missing in 43.5% of the cases, where as age information was missing for only 2% of the cases. As Tabachnik and Fidell suggest, we looked for the missing pattern. They suggest two ways to deal with missing data: dropping the cases with missing data or deleting the variables. If a case is missing too many data, dismissing or dropping the case from the dataset is the first alternative; however, if only certain variable information is missing for too many cases, then just deleting the variable is suggested. Since all the cases in the dataset had all the other information except for the missing project end use and project type, we deleted these two variables for multivariate analysis. Nevertheless, in order to recognize their presence in our data, we presented available frequency counts for these variables. The age variable was only missing for 2% of the cases, per literature suggestion we have left it as is. However, statistical software when conducting multivariate analysis, disregards these cases automatically.

Finally, after the screening process was done, the final dataset was produced for further main data analysis.

**3.4.1.2 Univariate Analysis for Explaining Data**

Frequency analyses were performed on each variable listed in Table 4 to reach a general understanding of accidents involving heavy construction equipment and those factors that may be associated with them. This analysis not only gave us an understanding but also helped us to produce an overview of the data.

We used bar charts to make comparisons between the levels of variables. We included the percentages and frequency counts on each bar graph. The findings of the frequency analysis on the dataset consisting of 1065 cases involving selected heavy construction equipment were graphed and tabulated. These findings are presented in Chapter 4, Univariate Analysis Findings section of this dissertation.

**3.4.2 Bivariate Analysis - Contingency Tables (Crosstabulation)**

After conducting the univariate analysis to investigate whether a significant relationship between pairs of variables existed, we carried out a bivariate analysis.

Bivariate Analysis is defined as "the analysis of two categorical variables (nominal or ordinal) simultaneously, for the purpose of determining the empirical relationship between them" (Babbie, 2010). As previously mentioned, one of the objectives of this study was to identify the factors that may have an association with the degree of injury. Therefore, bivariate analysis was performed by developing contingency tables using our dataset.

A contingency table (crosstabulation) is a table in matrix form which has rows representing one categorical variable and columns representing another variable. For example, when we analyze a variable with K level response levels and another categorical variable with C level response levels for a relationship, we have to create a contingency table which has K x C number of cells. Each cell shows us the observed counts, which shows frequency distribution of one variable separately for each category of another variable.

Once the contingency table is established and the cells are filled with frequencies, the next step is to examine the relationship. Sims (1999) suggests that an appropriate statistical test to accomplish this is the Pearson chi-square statistics.

The pearson chi-square compares the observed counts with those that would be expected if there were no association between two variables (Elliot and Woodward, 2006). There are certain assumptions that have to be met before conducting the Pearson chi-square test. If any one of these assumptions is not met, one cannot perform it and must select a different test. Assumptions are as follows:

1 – For the test to be meaningful, it is imperative that each case contributes to only one cell of the contingency table.

2- Contingency tables have to have a maximum of 20% of expected frequencies below 5. No expected frequencies should be below 1. (Fields, 2005)

Once these assumptions are met the chi square value is computed. The pearson chi-square value can be computed based on the following equation:

$$\chi^2 = \sum_{i=1}^{n} \frac{(\mathrm{O_i} - \mathrm{E_i})^2}{\mathrm{E_i}} \quad \text{..........Equation 1}$$

Where; O is the observed frequency number in the "i" cell

E is the expected frequency value in the "i' cell, and

n is the number of cells in the table.

The expected value of a cell is calculated by multiplying the total observed frequencies for the row containing the cell times the total observed frequencies for the column containing the cell, and then dividing it by the total number of the sample.

The pearson chi-square tests the hypothesis that the row and column variables are independent or dependent. For our study the null hypothesis that we formulated was

$H_o$ = There is no association between the variable and degree of injury

$H_a$ = There is an association between the variable and degree of injury

Once the pearson-chi square value is calculated, one has to calculate a p-value based on the Pearson chi-square value and degree of freedom. The degree of freedom is calculated by

$$d_f = (\,number\ of\ columns - 1) \times (numberof\ rows - 1) \quad \text{..........Equation 2}$$

The p-value is the probability value that is used for hypothesis testing by the Pearson chi-square test. After finding the p-value, one can decide whether the result is significant or not. Most common practice for significance level is 0.05. Therefore, a p-value less than 0.05 is accepted as significant, allows the researcher to reject the null hypothesis ($H_o$) of no association and conclude that there is an association between variables.

If the null hypothesis is rejected, the next step is to determine the strength of this relationship. To do so, one has to calculate Phi or Cramer's V values. Phi is a chi-square-based measure of association that involves dividing the Pearson chi-square value ($\chi^2$) by the sample size ($N$) and taking the square root of the result (Equation 3). Thw phi value can be calculated for only 2x2 contingency tables.

$$\varphi = \sqrt{\frac{\chi^2}{N}} \quad \text{.......................................................................Equation 3}$$

Cramer's V is a measure of association based on the chi-square in tables which have more than 2x2 rows and columns. It does not have the limitations of the phi value. Cramer's V can be calculated as

$$V = \sqrt{\frac{\chi^2}{N \times (k-1)}} \quad \text{.................................................................Equation 4}$$

Where, $\chi^2$ is the Pearson chi-square value

N is the total observation number

k is the number of rows or the number of columns in the contingency table
whichever is less

After this parameter is calculated, the scale given below can be used to interpret the strength of the relationship. In this study, the scale was chosen based on a previous researcher's suggestion. Healey (2011) suggests that a $\Phi$ or Cramer's V values indicate the following:

* 0-.33 – weak;
* .34-.66 – moderate; and
* .67-1.0 – strong.

One useful feature of the contingency table analysis additional to relationship investigation is the ratio it produces, the odds ratio (OR). It is defined in the Dictionary of Statistics (Everit and Skrondal, 2010) as; “the ratio of the probabilities of the two possible states of a binary variable”. Elliot and Woodward (2006) suggested that for a retrorespective study the appropriate measure of risk is the odds ratio, whereas for a prospective study it is appropriate to use relative risk, defined as “a measure of the association between exposure to a particular factor and risk or probability of a certain outcome”. Odds ratio is commonly used in the medical sciences in order to measure the risk associated with an exposure. The OR represents the odds that an outcome (dependent variable) will occur in the presence of an exposure (independent variable), compared to the odds of the outcome occurring in the absence of that exposure (Szumilas, 2010).

In light of this information we can write the formula for the OR as follows:

$$OR_{PRESENCE/ABSENCE} = \frac{\left(\frac{OCCURANCE\ OF\ OUTCOME}{ABSENCE\ OF\ OUTCOME}\right) WHEN\ EXPOSURE\ PRESENT}{\left(\frac{OCCURANCE\ OF\ OUTCOME}{ABSENCE\ OF\ OUTCOME}\right) WHEN\ EXPOSURE\ ABSENT} \text{.........................Equation 5}$$

This equation was used to compute the OR for each 2x2 contingency table analyzed in this study.

If the calculated OR is less than 1, it implies that exposure has a lowering effect on the risk of outcome occurrence. An OR greater than 1 is simply interpreted as the exposure having an increasing effect on the outcome occurrence. A value of 1 suggests that the exposure neither has increasing nor decreasing effect on the outcome variable.

In view of this information, this study used the contingency table analysis to research the possible associations between variables. The first step was selecting the dependent variable. The objective of this study as mentioned before was to identify the factors associated with the accident outcome and to quantify the risk of fatal injury with this association. Hence, the degree of injury variable, a binary variable, was chosen as the dependent variable. Other variables served as the independent variables. These variables were previously listed in Table 4.

We conducted a contingency table analysis on two groups. The first group is called heavy construction equipment operators, and the second group is called on-foot workers. The reason for this differentiation is that there are different hazard exposures for these two groups on a construction site. For example, whereas seat belt usage is an important exposure for an operator, it has no relation to on-foot workers. In other words there is no logical reason to evaluate and investigate any association for on-foot workers. Another example is the back-up alarm presence or condition; these variables would normally have no effect on possible injuries for heavy construction equipment operators. Therefore, both groups were individually studied. It should also be mentioned that in order to facilitate the understanding of the analysis, 2x2 and 2xk analysis results were performed separately.

The findings of the contingency table analysis on the dataset, 1065 cases involving selected heavy construction equipment, were tabulated. These findings are presented in Chapter 4 – Crosstabulation Analysis Findings.

### 3.4.3 Logistic Regression Analysis and Modeling

Logistic regression is a mathematical modeling approach which describes the occurrence or non-occurrence of an event. It allows one to predict a discrete outcome (such as group membership) from a set of input variables that may be continuous, discrete, dichotomous, or a mix (Tabachnick and Fidell, 2007). The main goal of the logistic regression analysis is to find the best yet reasonable model to describe the relationship between a dependent (response) and a set of independent (predictor or explanatory) variables.

The main difference between logistic regression analysis and linear regression analysis lies in the type of response variable. Logistic regression requires a categorical variable whereas linear regression requires a continuous variable. Logistic regression also differs according to the type of categorical data. If the response variable is discrete, in other words it only has two levels, a “binary logistic regression” analysis must be performed; however, if the response variable is more than two levels one has to conduct “multinomial logistic regression” analysis.

The logistic regression does not have the requirement of the independent variables to be normally distributed and linearly related, nor does it call for equal variance within each group. These features make logistic regression attractive for researchers.

As previously mentioned, we investigated the relationship of independent variables to our dependent variables by conducting contingency table analysis. This gave us an understanding on how each individual variable is associated with the dependent variable, and how this association shows itself in terms of risk. However, it did not give us any indication of the combined effects of independent variables on the dependent variable at the same time and how the risk of fatal injury changes with this combined effect. Therefore, our research questions became the following:

1. Can the degree of an accident be predicted from the set of input variables? Which variables predict the degree of injury at a significant level?

2. How does each variable influence the degree of injury in the presence of others?

3. Does a particular variable increase or decrease the probability of degree of injury?

Linear regression analysis creates a model which is linear, and the dependent variable (Y) is predicted from the equation of a straight line by multiplying each independent variable by its coefficient and summing them:

$$Y = \beta_0 + \beta_1 . X_1 + \beta_2 . X_2 + \ldots + \beta_n X_n + \varepsilon \quad \text{.......... Equation 6}$$

Where, Y = dependent variable; $\beta_0$ = exposure variable or constant, $\beta_{1..n}$ = coefficients, $X_{1..n}$= independent (predictor) variables

However, logistic regression produces a nonlinear model; therefore, instead of predicting the value of Y (dependent variable) from the predictor variable $X_{1..n}$ , we predict the **probability** of Y occurring given the known values of $X_{1..n}$ (Fields, 2005).

The significance of logistic regression lies in the logistic transformation. In order to perform this transformation and predicting the dependent variable probability, one can write the probability function as

$$\frac{p}{1-p} = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \ldots + \beta_n.X_n + \varepsilon \quad \text{Equation 7}$$

Where p is the probability of occurrence of an event and 1-p is the probability of non-occurrence.

Now, the problem with this equation is that the right side of the equation can get any value between - ∞ to + ∞. On the other hand, the left side of the equation cannot be negative. To overcome this problem, the logit transformation equation must be used, and it is formulated as

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) \quad \text{Equation 8}$$

where the natural log of the probability of being in one group (occurrence of an event) divided by the probability of being in the other group (non-occurrence of an event), which is the natural log of the odds of the occurrence of an event.

When this logit transformation is applied to Equation 7, that equation becomes

$$\ln\left(\frac{p}{1-p}\right) = \ln(\beta_0 + \beta_1.X_1 + \beta_2.X_2 + \ldots + \beta_n.X_n + \varepsilon) \quad \text{Equation 9}$$

In logistic regression, the dependent variable is coded in a certain way in order to distinguish the difference between the occurrence and non- occurrence of an event. The simplest way to code the dependent variable is assigning a value of 1 (Y=1) to event occurrence and 0 (Y=0) to no occurrence. It should be noted that 1 and 0 is only to distinguish the difference of outcome; it does not have a numerical value. In this study, the dependent variable, degree of injury, was coded accordingly; hence, fatal injury was coded as 1, and nonfatal injury was coded as 0. In our study P(Y) can also be indicated as $P(Y=1|X_1, X_2 \ldots X_n)$ which means the probability of accident resulting in fatal injury, and $1 - P(Y) = P(Y=0|X_1, X_2 \ldots X_n)$ denoting the non-occurrence of dependent variable, which is nonfatal injury.

In solving the Equation 9, the logistic regression equation from which the probability of Y is predicted becomes

$$P(Y) = \frac{1}{1+e^{-(\beta_0 + \beta_1 . X_1 + \beta_2 . X_2 + \ldots + \beta_n . X_n + \varepsilon)}} \qquad \text{Equation 10}$$

Where, $P(Y)$ = probability of Y occurring; e is the base of natural logarithm and $\beta_0$ represents exposure variable or constant, $\beta_{1..n}$ are the coefficients, and $X_{1..n}$ are the independent (predictor) variables. Such a function has the shape of an S. (Figure 9).

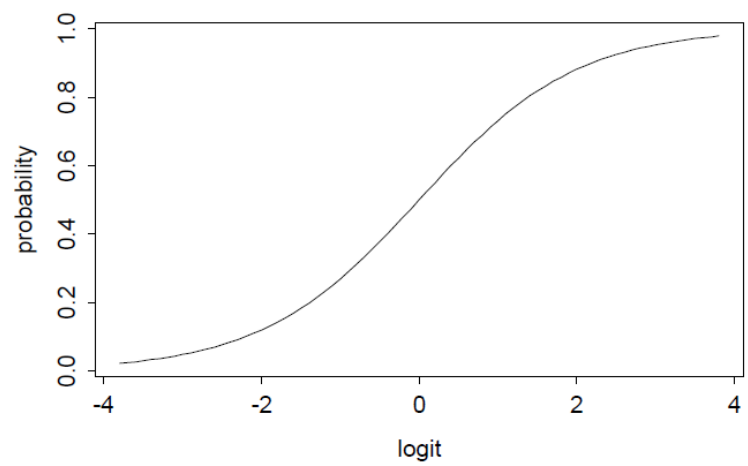


Figure 9: Logit function graph

Model creation, in other words, choosing the best model, is the challenge. In order to choose the best predictive model one has to check various numbers of tests which are produced also as an output of SPSS. These tests are discussed in the following paragraphs.

The first thing is to make sure that it meets the guidelines for "goodness-of-fit". This goodness-of fit is done by a parameter that checks the fit of the model. In order to do so, the log-likelihood needs to be calculated. The log-likelihood is based on summing the probabilities associated with the predicted and actual outcomes (Tabachnick and Fidell, 2007). When this log-likelihood reaches large values, it is an indication of a poorly fitting statistical model. Thus, this helps the researcher choose the best model for the analysis by comparing the log-likelihood values. This comparison, whether the log-likelihood is large or not, can be done by simply comparing the baseline (naive) model, one with only the constant, to other models with the predictor variables.

Log-likelihood= $\sum_{i=0}^{n}[\mathrm{Y_i}.\ln\left(\mathrm{P}(\mathrm{Y^*}_\mathrm{i})\right) + (1-\mathrm{Y_i})\,.\,(1-\mathrm{P}(\mathrm{Y^*}_\mathrm{i}))]$ ....................Equation 11

or

$\chi^2 = -2(LL(new) - LL(baseline))$ ....................................................................Equation 12

Where; LL (new) is the loglikelihood value for other variables in the model, and

LL (baseline) is the loglikelihood when only the constant is included in the model.

Since this loglikelihood test can produce a Chi-square value, one will need to determine the degree of freedom in order to identify the significance value. The degree of freedom is the number of variables in the new model minus the number of variables in the baseline model.

$df = k_{new} - k_{baseline}$..........................................................................................Equation 13

Another way to choose the best model is the improved prediction power. Even a bare model with only constant ($\beta_0$) without any predictor variable can predict the outcome. A model has to have a better predictive power in order to count as a reliable model. In other words, the most viable model is the model which gives the best prediction.

Other tests that need to be conducted can be listed as Wald's test, Hosmer and Lemeshow's $R_L$ and Exp (β). Wald's test is used to determine whether an independent variable is a significant predictor of the outcome. It is calculated as:

$$\text{Wald} = \frac{\beta^2}{SE_{\beta}{}^2} \quad \text{Equation 14}$$

Hosmer and Lemeshow's $R_L$ is a test which represents the measure of how much the goodness of fit improves as a result of the inclusion of predictor variables in each step (Fields, 2005). This allows the researcher to identify the important variables that have an effect on the model. Hosmer and Lemeshow's $R_L$ can be calculated as

$$R_L{}^2 = \frac{-2LL(NEW)}{-2LL(BASELINE)} \quad \text{Equation 15}$$

Exp(β) is the exponential value of the β coefficients, and its value represents the odds ratio. Therefore, Exp(β) represents the odds ratio of that predictor variable and how it affects the outcome. A change of one unit on the part of a change in the predictor variable multiplies the odds by Exp(β) (Tabachnik and Fidell, 2007).

#### 3.4.3.1 Data preparation for Logistic Regression Analysis

In this study, binary logistic regression analysis was conducted by using SPSS software. As previously mentioned, the binary dependent variable (degree of injury) was coded as 1 for fatal and 0 for nonfatal injuries; other binary independent variables were also coded as 0 and 1, whereas 0 indicates absence and 1 indicates the presence of whatever is indicated by the variable. For nominal independent variables with more than two levels, we coded them with numbers 1, ..n just to distinguish them. It should again be noted that a larger number does not have any superiority to a smaller number.

#### 3.4.3.2 Starting Logistic Regression Analysis and Model Selection

There are different methods to insert variables into SPSS software and to run analysis. In this study we used the stepwise backward method as the variable insertion method. The stepwise backward method is where all the predictor variables inserted into the model at the beginning of analysis and according to the statistical criterions mentioned above where insignificant variables are taken out until only all the significant variables are left in the model.

By using SPSS output tables the overall fit of the best model is assessed using the loglikelihood statistic. Reduction in this value told us that the model was better at predicting the degree of injury as a fatality than it was before the predictor variables were added. The classification table, which displays the cross-classification of the observed versus predicted values of the dependent variable was also examined in order to select the model with high percentage accuracy that to predict the group membership for a case. One criterion for us to look for in the classification table is the number of false negatives (Type II error). A type II error can be defined as classifying an event as a negative when actually it is positive. In our study, this definition shows itself as follows. If our model says the case will be a nonfatal injury, although in reality it was a fatal injury, then this case falls into the Type II error group. This is better for the accuracy of the model and its correct prediction power; this parameter was also taken into account when deciding on the model.

### 3.4.3.3 Model Validation

Validation of the logistic regression models is necessary to measure the performance of these models. If one doesn't apply validation to the model, this may result in poorly fitting results that inaccurately predict the future outcomes (Giancristofaro and Salmaso, 2003).

Generally, this can be conducted in two ways: external validation and internal validation. External validation is where a new sample set of data is obtained, and a previously developed model is applied on this dataset as it is. Internal validation is conducted by splitting the dataset in a certain ratio which is usually 60/40 or 70/30, then developing the model in the high number dataset and applying this model to the low number dataset, and measuring the accuracy of prediction.

We opted for the data splitting approach to validate our fitted models. Since the sample size is large enough, the data are split into two sets. The model subset cases were selected in a 70/30 ratio. To facilitate a random selection of cases, we used the Bernoulli distribution feature of the SPSS software. Bernoulli distribution (Azen and Walker, 2010) takes the values of 0 and 1; SPSS assigned the value of 1 randomly to 70% of the cases which we used to develop the model, and the remaining 30% was used to validate this data.

Three different models were developed for this research study by dividing the whole dataset into subsets. Figure 10 displays the models created and the sample size of each subset.

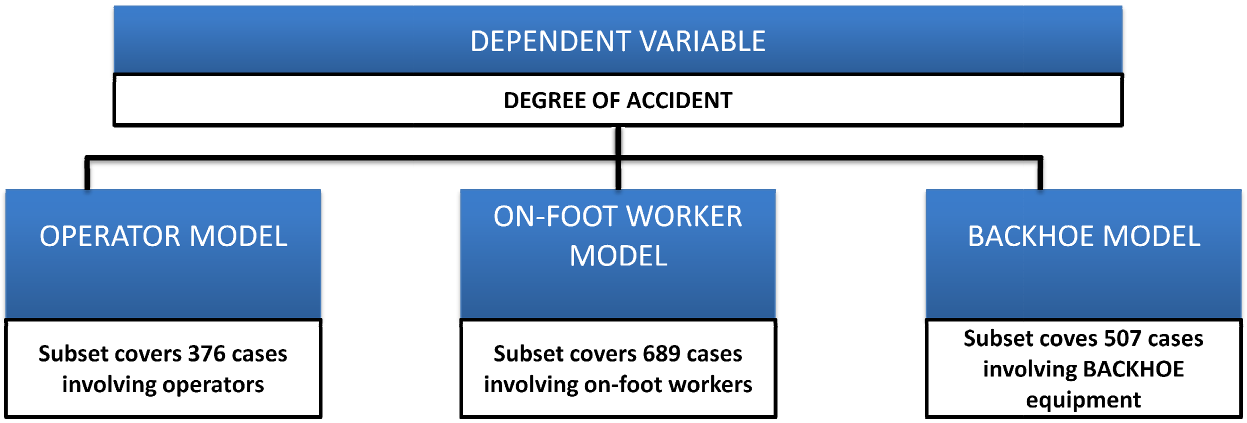


Figure 10: Binary Logistic Regression Models

The operator model was developed to identify variables that predict the degree of injury at a significant level, where operators of four specific earthmoving equipment are involved in an accident, and how these variables influence the degree of injury relative to others. Similarly, the on-foot worker model predicts the accident severity for the workers working around the backhoe, bulldozer, excavator or scraper. Finally, the backhoe model was an attempt to see if a predictive model could be developed and validated for a specific type of equipment.

The findings of the binary logistic regression analysis on the dataset were tabulated. These findings are presented in Chapter 4 – Binary Logistic Regression Analysis Findings section of this dissertation.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Univariate/Frequency Analysis Findings

Univariate analysis results are first presented in this chapter; results are organized according to 6 different characteristics as covered in Chapter 3. Univariate analysis, performed on the whole dataset, gives the researcher a general understanding of the dataset in hand; it also helps the researcher identify and filter some important cases according to the frequency count.

### 4.1.1 Time Characteristics

#### 4.1.1.1 Days of the week

The distribution of the accident count was analyzed among the 1065 cases. It was found that there were more accidents occurring on Monday and Thursday compared to the rest of the weekdays (see Table 5). When weekends were analyzed, it was found that less than 100 accidents occurred during the weekend, which represents 6.3% of the overall data used in this study. Further analysis was also conducted for the days of the week variable by using crosstabulation, and its results are discussed in the next section.

Table 5: Frequency distribution of days

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Monday* | 228 | 21.4 | 21.4 |
| *Thursday* | 219 | 20.6 | 42.0 |
| *Friday* | 193 | 18.1 | 60.1 |
| *Tuesday* | 192 | 18.0 | 78.1 |
| *Wednesday* | 166 | 15.6 | 93.7 |
| *Saturday* | 53 | 5.0 | 98.7 |
| *Sunday* | 14 | 1.3 | 100.0 |
| Total | 1065 | 100.0 | |

#### 4.1.1.2 Months of the year

When months were analyzed, the analysis revealed that June and August showed high total accident counts, which appeared to be the dangerous months in the dataset, closely followed by September and October (see Table 6). Due to the United States' geography, there are different climate observations in different states throughout the year. This allows contractors and subcontractors to work on construction projects in different states throughout the US. Therefore, the frequency of accident occurrence in months was expected to be close.

Table 6: Frequency distribution of months

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *January* | 65 | 6.1 | 6.1 |
| *February* | 71 | 6.7 | 12.8 |
| *March* | 84 | 7.9 | 20.7 |
| *April* | 92 | 8.6 | 29.3 |
| *May* | 82 | 7.7 | 37 |
| *June* | 116 | 10.9 | 47.9 |
| *July* | 86 | 8.1 | 56 |
| *August* | 116 | 10.9 | 66.9 |
| *September* | 99 | 9.3 | 76.2 |
| *October* | 94 | 8.8 | 85 |
| *November* | 91 | 8.5 | 93.5 |
| *December* | 69 | 6.5 | 100 |
| Total | 1065 | 100.0 | |

#### 4.1.1.4 Year

The dataset used in this study is from 1982 to 2008. Figure 11 displays the accident distribution among the years. The accident count is low in 2008 due to the available data in the IMIS database. When the data collection was finished for the study, IMIS didn't have any reports in May through December. It should also be noted that due to the recession in the US, declining job opportunities may have had an effect on the number of accidents. One can easily observe that the number of accidents involving backhoes, excavators, bulldozers and scrapers fluctuated from 1983 to 2008.

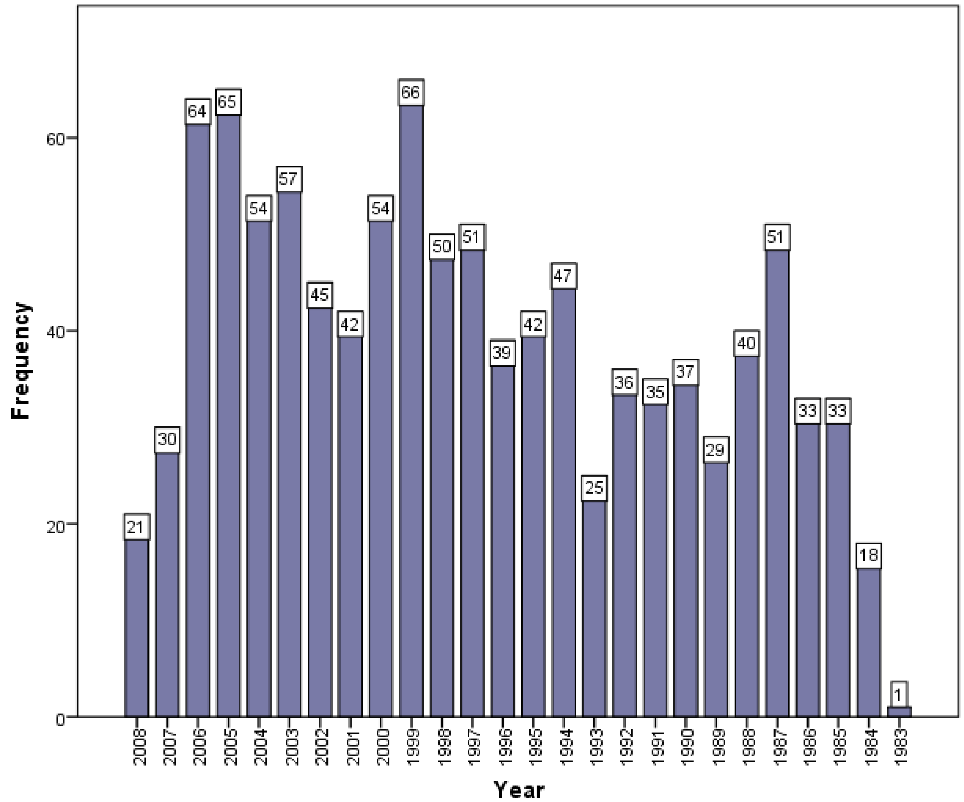


Figure 11: Distribution of accident counts in years

**4.1.2 Project Characteristics**

**4.1.2.1 Project type**

These accidents were recorded by different OSHA agencies in different states; some of the variable information was not available or detailed enough to assign a value, such as the project type variable was not recorded in the reports for 463 cases, which represents 43.5% of the dataset. But among the provided information, new project or new addition category came first in the frequency count (Table 7). This raises a flag for workers who are assigned to new projects or new additions.

Table 7: Frequency distribution of project types

| | Frequency | Percent | Valid Percent |
|---|---|---|---|
| *New project or new addition* | 390 | 36.6 | 64.8 |
| *Alteration or rehabilitation* | 78 | 7.3 | 13.0 |
| *Other* | 71 | 6.7 | 11.8 |
| *Maintenance or repair* | 37 | 3.5 | 6.1 |
| *Demolition* | 26 | 2.4 | 4.3 |
| *Total* | 602 | 56.5 | 100.0 |
| *Missing System* | 463 | 43.5 | |
| Total | 1065 | 100.0 | |

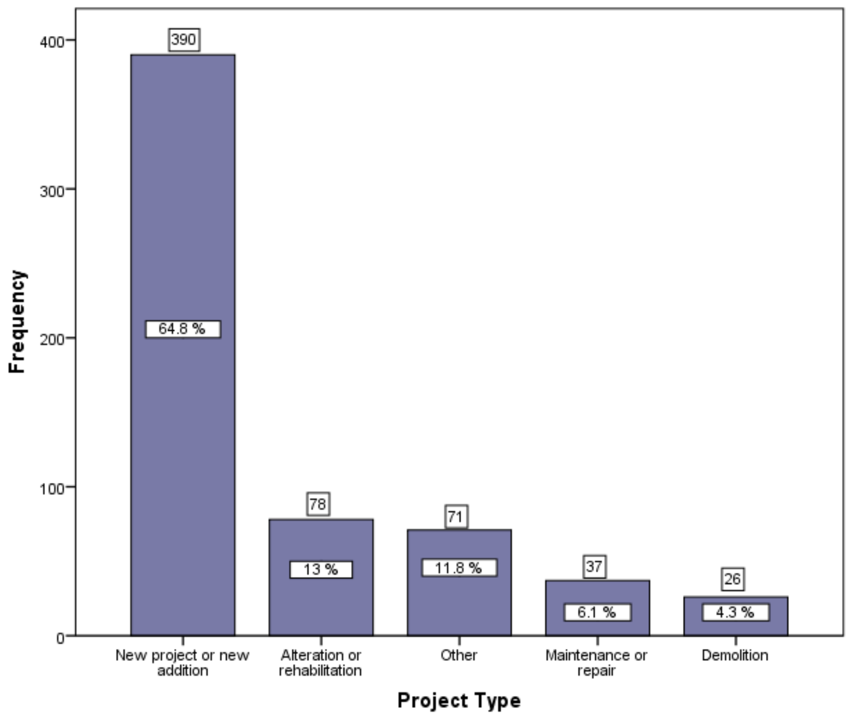


Figure 12: Frequency distribution of project types

#### 4.1.2.2 Project end use

The same situation also applies to the project end use variable; no information was provided for 463 cases, indicating the end use of the project which represents 43.5% of the cases. However, project end use identified as heavy/civil (tower, tank, storage elevator, shoreline development, dam, reservoir pipeline, excavation, landfill, powerline, transmission line, and other heavy construction) accounted for 18% of the accidents, and highway end use followed this with 12.3 % (Table 8).

Table 8: Frequency distribution of project end use

| | Frequency | Percent | Valid Percent |
|---|---|---|---|
| *Heavy/Civil* | 192 | 18.0 | 31.9 |
| *Highway* | 131 | 12.3 | 21.8 |
| *Residential* | 119 | 11.2 | 19.8 |
| *Commercial* | 63 | 5.9 | 10.5 |
| *Other Building* | 55 | 5.2 | 9.1 |
| *Industrial* | 42 | 3.9 | 7.0 |
| *Total* | 602 | 56.5 | 100.0 |
| *Missing System* | 463 | 43.5 | |
| Total | 1065 | 100.0 | |

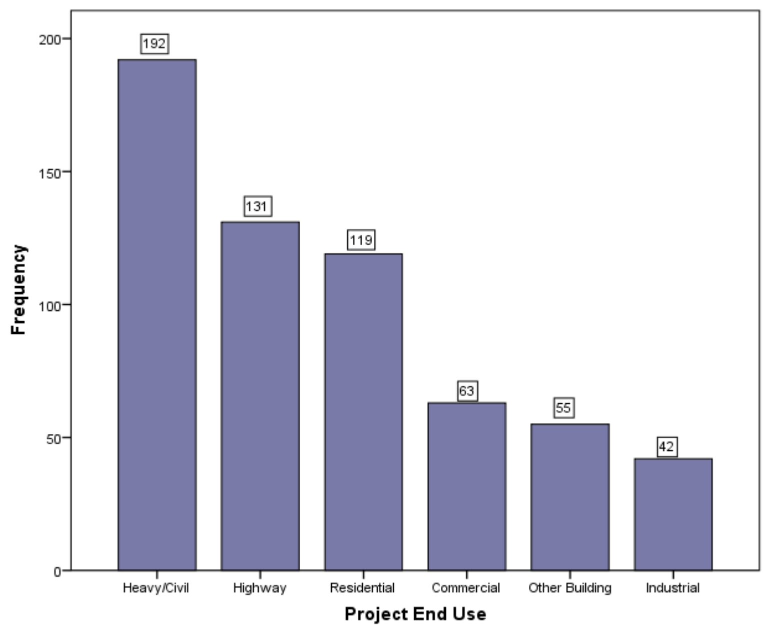


Figure 13: Frequency distribution of project types

### 4.1.3 Equipment Characteristics

#### 4.1.3.1 Equipment type

The multitasking design of backhoes makes them popular at construction sites. Their loading and excavating capabilities make them indispensable compared to the other equipment available to contractors.

Table 9: Frequency distribution of equipment types

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Backhoe* | 507 | 47.6 | 47.6 |
| *Bulldozer* | 227 | 21.3 | 68.9 |
| *Excavator* | 224 | 21.0 | 90.0 |
| *Scraper* | 107 | 10.0 | 100.0 |
| Total | 1065 | 100.0 | |

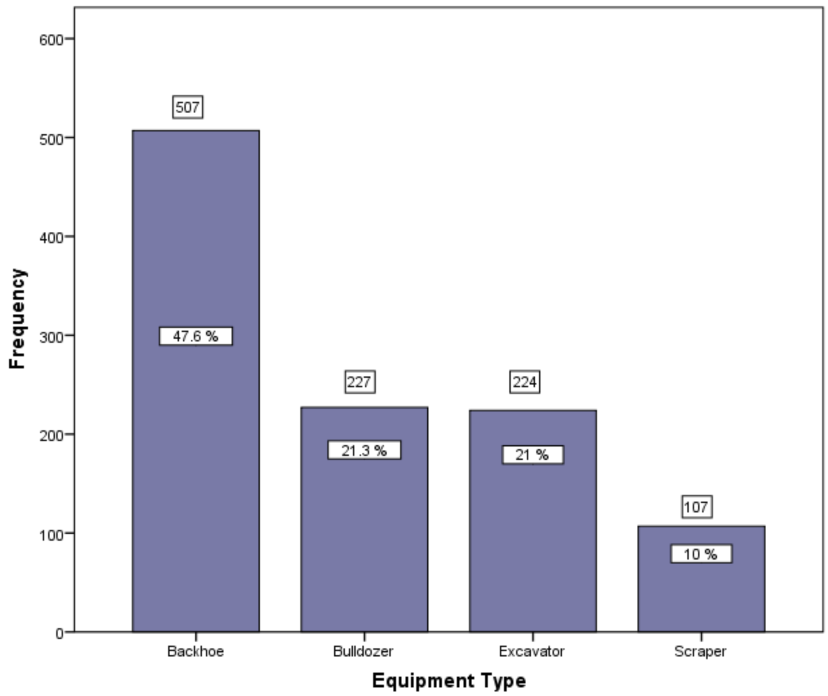


Figure 14: Frequency distribution of equipment types

Figure 14 displays the accident frequency of backhoes compared to other earthmoving equipment analyzed in this study. Of the overall data, 47.6% or 507 accidents involved backhoes (see Table 9). This finding also points to the need for further analysis; hence, crosstabulation was applied specifically to backhoe accidents in order to gain insights into contributing factors. These findings and results are discussed later in this dissertation.

#### 4.1.3.2 Equipment part involved in the accidents

Heavy construction equipment are large machines, so due to their size, construction personnel on site are exposed to hazards. When the narrative part of the collected accident reports mention some terms as the cause of the injury, such as equipment tracks, outriggers and equipment superstructure, then these accidents were assigned to the equipment body involvement in the accident category. A total of 523 accidents were identified as involving equipment body/superstructure.

Since most of the attachments are vertically and horizontally moving parts, a danger zone appears for the on-foot workers in the vicinity of the heavy construction equipment. Equipment moving part involvement including buckets, blades etc. was counted in 398 accidents.

There were 134 accidents in the carried/pushed/pulled/lifted load category due to the fact that these four types of equipment were mostly used in earthwork (e.g. excavation, grading, and backfilling). However, it is also known that backhoes and excavators are sometimes used for rigging purposes on certain projects, such as pipe installation. Carried/pushed/pulled/lifted loads were responsible for 12.67% of the accidents, and most of these accidents happened due to lack of proper maintenance or inspection. Typically, either chain hooks failed or the chain itself failed.

Lastly, 10 accidents were observed for other reasons, such as overhead power lines, underground utility lines and so on. (Table 10)

Table 10: Frequency distribution of equipment part involved in the accidents

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Body/Superstructure* | 523 | 49.1 | 49.1 |
| *Attachment* | 398 | 37.4 | 86.5 |
| *Carried/Lifted Load* | 134 | 12.6 | 99.1 |
| *Other* | 10 | .9 | 100.0 |
| Total | 1065 | 100.0 | |

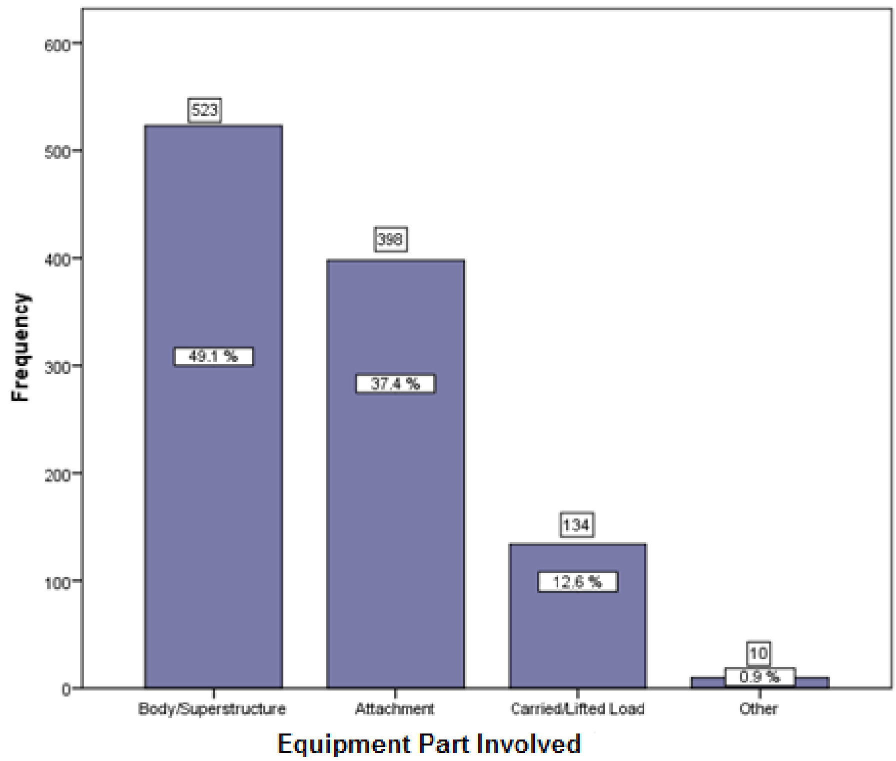


Figure 15: Frequency distribution of equipment involvement in the accidents

#### 4.1.3.3 Rollover protection structure (ROPS) presence

OSHA construction regulation 1926 Subpart W mandates that “material handling equipment manufactured on or after September 1, 1972; including but not limited to all rubber-tired, self-propelled scrapers, rubber-tired dozers, crawler tractors, crawler-type loaders, and motor graders, with or without attachments, that are used in construction work shall equipped with a rollover protection structure (ROPS) which meet the minimum performance standards prescribed in 1926.1001 and 1926.1002, as applicable.” (OSHA, 2009) Therefore, whenever a citation was issued to a company due to the absence of rollover protection structure (ROPS) on equipment, that accident was assigned to the “not present” category.

As can be seen in Table 11, 26 accidents (2.4%) were identified for missing ROPS. This is due to the above mentioned equipment mostly being sold with ROPS installed by the manufacturers. A further study was carried out especially for operators since main purpose of the ROPS device is to protect operators in the event of a rollover.

Table 11: Frequency distribution of equipment rollover protection presence

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Present* | 1039 | 97.6 | 97.6 |
| *Not Present* | 26 | 2.4 | 100.0 |
| Total | 1065 | 100.0 | |

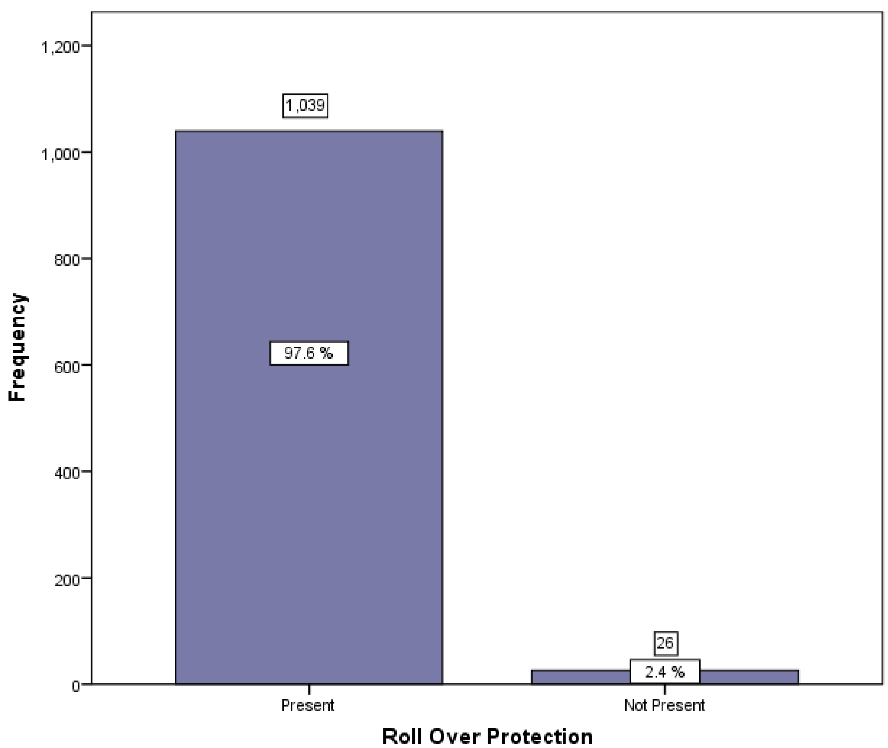


Figure 16: Frequency distribution of equipment ROPS presence

McCann (2006) mentioned the importance of the ROPS in his research. He also underlined a fact that as much as ROPS is protective, it may become a death trap for operators if their equipment is involved in a rollover or overturn accident and their seatbelts are not fastened. We also noted that, this was a common mistake made by operators in the event of rollover either they were ejected due to not fastening their seat belts or they were trying to jump off the rolling equipment, as a result they were crushed between the ROPS and ground resulting in a fatal injury in most cases.

#### 4.1.3.4 Seat belt presence in equipment

Again, just like the ROPS cases, seat belt presence or absence was also identified by studying the OSHA citations. OSHA regulation Title 29 CFR 1926.602(a)(2)(i) states that for “earthmoving equipment: such as, scrapers, loaders, crawler or wheel tractors, bulldozers, off-highway trucks, graders, agricultural and industrial tractors, and similar, seat belts shall be provided on all equipment ,and shall meet the requirements of the Society of Automotive Engineers, J386-1969, Seat Belts for Construction Equipment.” (OSHA, 2009)

Seat belt cited accidents showed that in 64 (6 % of the cases) involved, seat belts were either missing or inoperable. (Table 12) This is also one of the variables which should be studied for the operators only in order to identify in which cases even though seat belt was present, it was not fastened.

Table 12: Frequency distribution of seat belt presence in equipment

| | **Frequency** | **Percent** | **Cumulative Percent** |
|---|---|---|---|
| *Present* | 1001 | 94.0 | 94.0 |
| *Not Present* | 64 | 6.0 | 100.0 |
| Total | 1065 | 100.0 | |

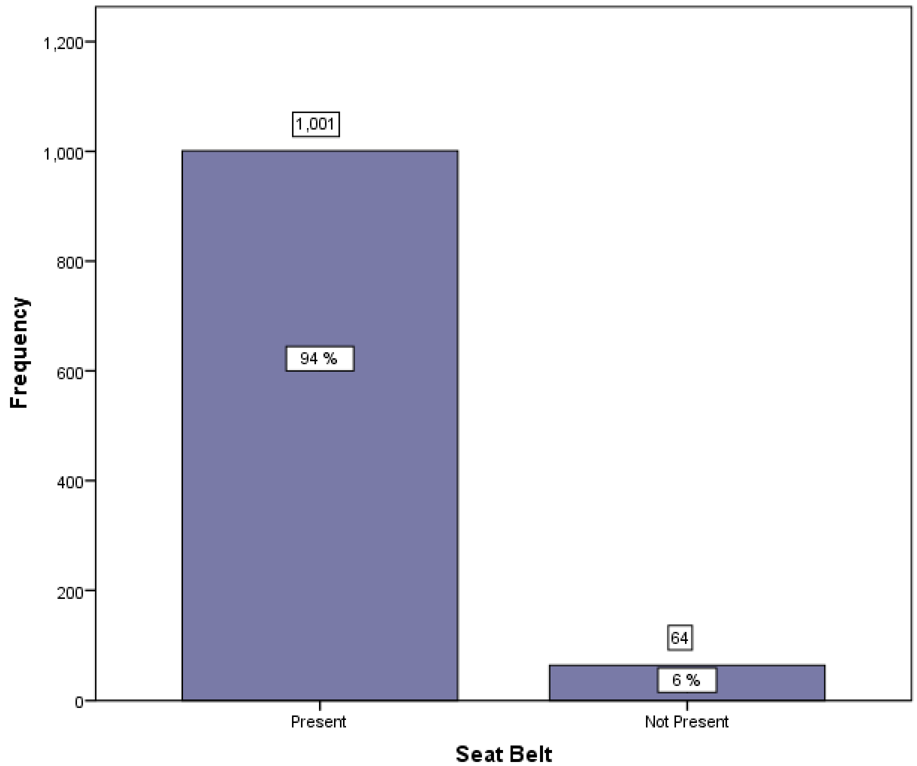


Figure 17: Frequency distribution of seat belt  presence in equipment

#### 4.1.3.5 Back-up alarm condition on equipment

Equipment backup alarms are one of the most common sounds one can notice on construction sites. Their loud sound alerts on-foot workers close to the equipment when they are backing up. When these alarms are not operable or not loud enough, often mixing with regular site background noise, this creates an imminent danger for the on-foot workers.

Therefore, in order to identify the missing back-up alarms, OSHA citations which were given as recorded in the collected accident data were studied. OSHA regulations Title 29 CFR 1926.601 and 1926.602 state that all trucks and mobile construction equipment must be equipped with an operable back-up alarm.(OSHA, 2009) Yet, these alarms must be loud enough to be audible over the surrounding noises and should be activated whenever equipment is in reverse motion (Hinze and Teizer, 2011).

Table 13: Frequency distribution of back-up alarm condition in equipment

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Working* | 987 | 92.7 | 92.7 |
| *Not Working* | 78 | 7.3 | 100.0 |
| Total | 1065 | 100.0 | |

In the dataset, 7.3% (78) of the accidents were cited for audible back-up alarm missing or inoperable as seen in Table 13 and Figure 18. Hinze and Teizer (2011) conducted a study on fatalities in which vision or lack of good visibility was the principle factor or contributing cause. They examined 594 cases which involve heavy construction equipment and motor vehicles in construction sites. They also researched the vehicle direction of travel and the use of operable back-up alarms. In their dataset, they identified 69 cases of equipment in reverse motion, and 56 of these cases were identified as back-up alarms not working. They found that the scraper had the highest frequency count (26%), whereas the backhoe and excavator had the lowest percentage (4%). However, they did not differentiate these findings according to worker type.

In another study, McCann (2006) speculated that standard backup alarms do not seem to be a solution due to other competing noises in the construction environment and pointed out the need for more research in construction for different back-up warning systems.

Therefore, we carried out further analysis for on-foot workers only since back-up alarm is intended to alert these workers. Findings are presented in the crosstabulation section.

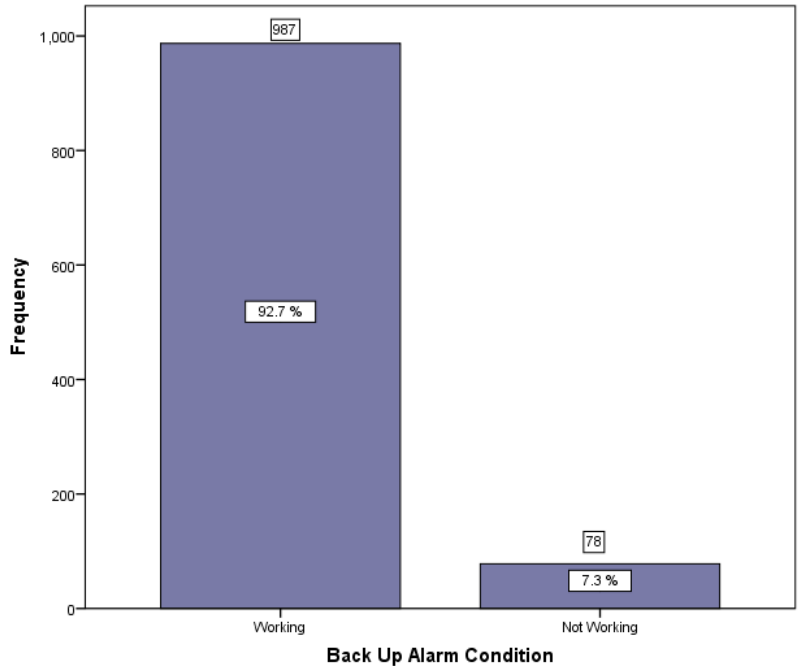


Figure 18: Frequency distribution of back-up alarm condition in equipment

### 4.1.4 Accident Characteristics

#### 4.1.4.1 Degree of injury

Degree of injury among the 1065 cases mostly resulted in fatalities. One can observe in Table 14 that the majority of the accidents (68.3%) included in the analysis resulted in fatal injury in comparison to 31.7% which were nonfatal. This high number of fatal injury also shows how life threatening heavy construction equipment related accidents are. It was clear after reviewing all the case abstracts that non-serious heavy construction equipment accidents are rare; even when they do not result in fatal injury, they lead to a hospitalized injury.

Table 14: Frequency distribution of degree of injury

| | **Frequency** | **Percent** | **Cumulative Percent** |
|---|---|---|---|
| *Fatal* | 727 | 68.3 | 68.3 |
| *Nonfatal* | 338 | 31.7 | 100.0 |
| Total | 1065 | 100.0 | |

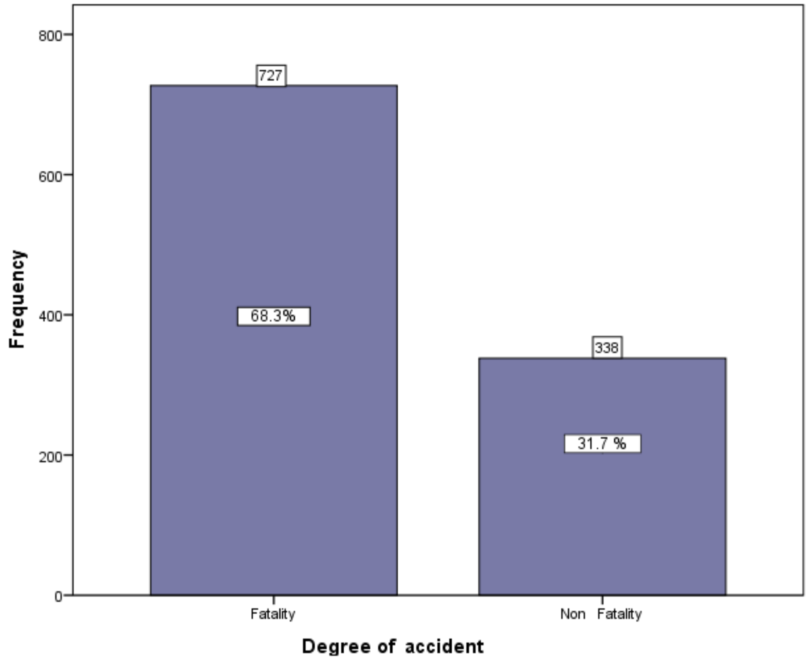


Figure 19: Frequency distribution of degree of injury

#### 4.1.4.3 Back-up motion presence in an accident

The travel direction of the equipment is also an important factor in this study. The limited number of studies on heavy construction equipment that we identified also calls for further research on blind spots. Due to the size of heavy construction equipment there are bigger blind spots while they are in reverse motion. Therefore, we identified the cases where heavy construction equipment was in reverse motion.

According to Table 15, 17.9% of the accidents occurred when equipment was in back-up motion. It is important to note the moving direction of the equipment; the literature suggests that back-up accidents are the main concern for on-foot workers.

Table 15: Frequency of back-up motion presence in accident

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Not Present* | 874 | 82.1 | 82.1 |
| *Present* | 191 | 17.9 | 100.0 |
| Total | 1065 | 100.0 | |

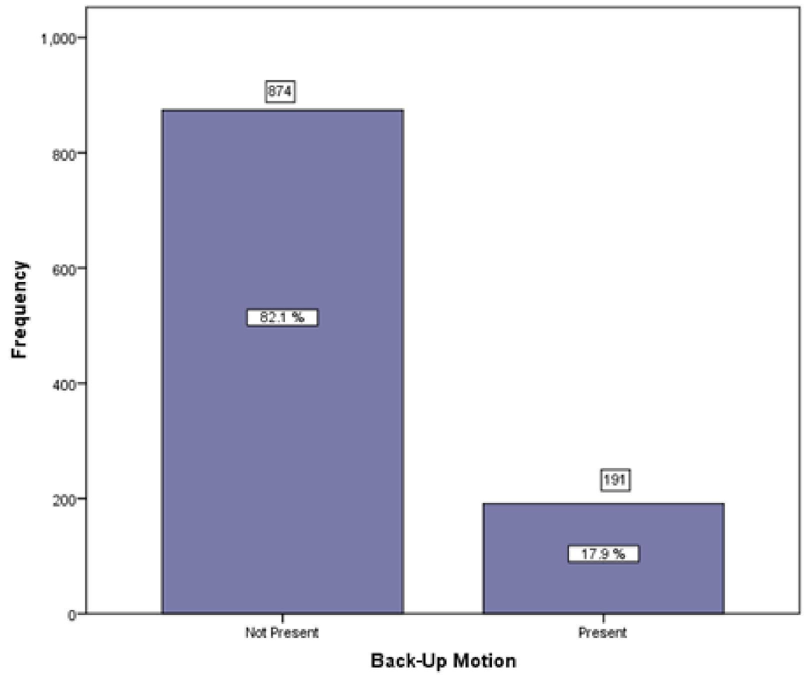


Figure 20: Frequency of back-up motion presence in accident

#### 4.1.4.4 Event type

Each year, OSHA classifies the most frequently occurring event types in the construction industry and categorizes them in four main headings called “Focus Four”, which are struck-bys, caught in/or betweens, electrocutions and falls.

As seen in Table 16, a high percentage of the cases 54.6% (582) were identified as struck-by accidents. The caught in/or between exposure was identified in 287 accidents. Electrocution, fall from elevation and others (ingestion, fall on the same level, bite/sting, rubbed/abraded) followed these, respectively, by 6.4%, 5.6%, and 6.4%.

Table 16: Frequency of event types in accidents

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Struck-by* | 582 | 54.6 | 54.6 |
| *Caught in/or between* | 287 | 26.9 | 81.6 |
| *Electrocution* | 68 | 6.4 | 88.0 |
| *Other* | 68 | 6.4 | 94.4 |
| *Fall from elevation* | 60 | 5.6 | 100.0 |
| Total | 1065 | 100.0 | |

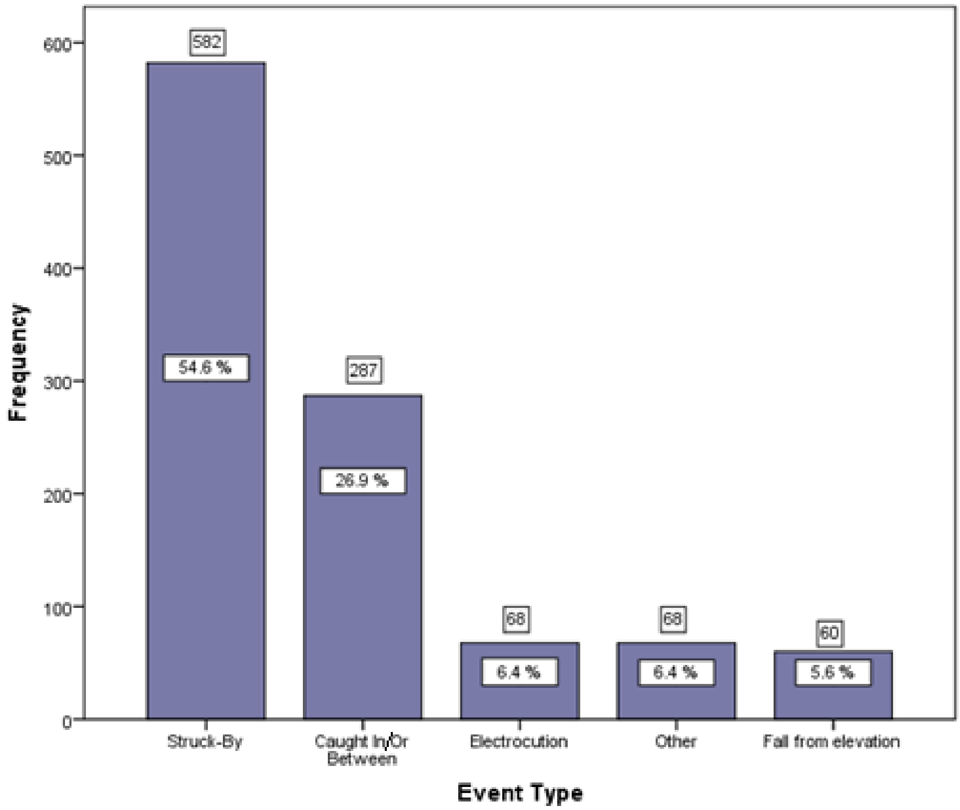


Figure 21: Frequency of event types in accidents

#### 4.1.4.5 Event details

In order to gain deeper knowledge of event type, the event detail variable was created by the researcher. The main idea was to identify and then analyze the specific event type individually. Table 17 displays each event type in detail, with 285 cases identified as struck-by equipment; the second most frequent event detail was caught in/or between equipment and a stationary object (209). Struck-by attachment and struck-by falling object followed these with 138 and 82 frequency count, respectively.

Table 17: Frequency of event details in accidents

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Struck-by equipment* | 285 | 26.8 | 26.8 |
| *Caught in/or between equipment and stationary object* | 209 | 19.6 | 46.4 |
| *Struck-by attachment* | 138 | 13.0 | 59.3 |
| *Struck-by falling object* | 82 | 7.7 | 67.0 |
| *Electric shock* | 68 | 6.4 | 73.4 |
| *Fall from elevation* | 60 | 5.6 | 79.1 |
| *Struck-by falling attachment* | 52 | 4.9 | 83.9 |
| *Fire/explosion* | 34 | 3.2 | 87.1 |
| *Caught in/or between multiple equipment* | 34 | 3.2 | 90.3 |
| *Trapped* | 31 | 2.9 | 93.2 |
| *Caught in/or between falling material* | 25 | 2.3 | 95.6 |
| *Struck-by swinging/flying object* | 25 | 2.3 | 97.9 |
| *Caught in/or between equipment and moving object* | 19 | 1.8 | 99.7 |
| *Other* | 3 | .3 | 100.0 |
| Total | 1065 | 100.0 | |

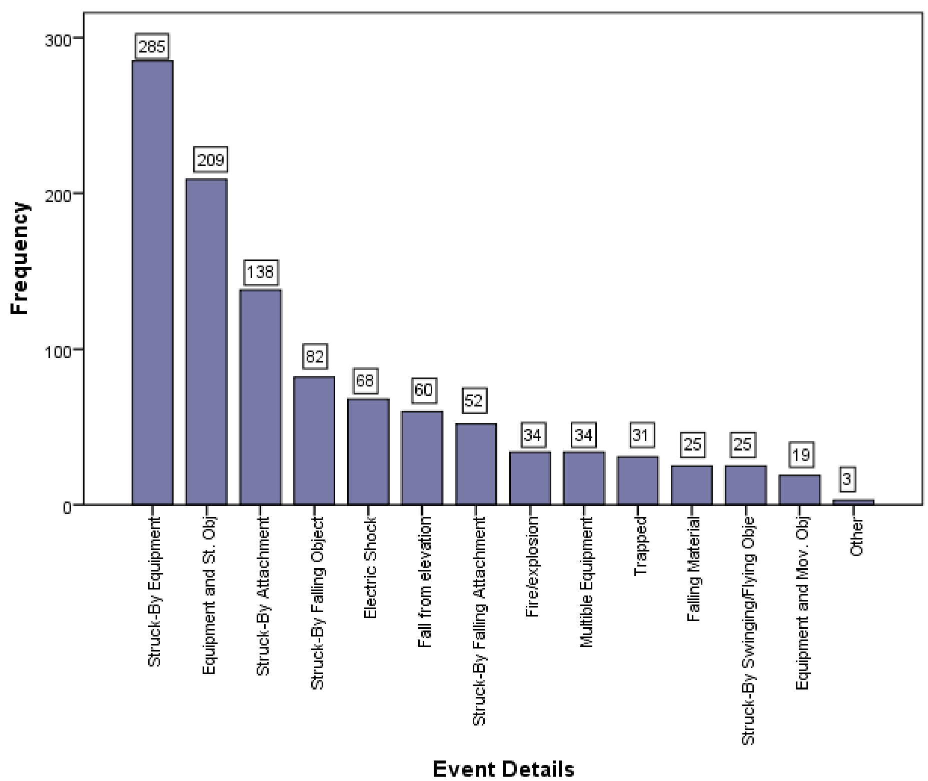


Figure 22: Frequency of event details in accidents

#### 4.1.4.6 Environmental factor in accidents

A construction site is a dynamic environment; it changes shape each day as the project progresses; the number and kinds of trades, as well as the number and kinds of equipment change from day to day; hence, the type of hazards change accordingly. To understand the environmental factors identified by OSHA during the investigation of cases, it was observed that 10 different environmental factors contributed to accidents. Some researchers also identify these factors as “Unsafe Conditions” (Chi et. al., 2012)

When these environmental factors were analyzed, as shown in Table 18, material handling equipment/method was observed in 36% of the cases, while work-surface/facility-layout condition was observed in 11.9%. Blind spot accounted for 4.1% of the total cases.

Table 18: Frequency of environmental factor in accidents

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Materials handling equip./method* | 383 | 36.0 | 36.0 |
| *Overhead moving/falling object action* | 148 | 13.9 | 49.9 |
| *Squeeze point action* | 145 | 13.6 | 63.5 |
| *Work-surface/facility-layout condition* | 127 | 11.9 | 75.4 |
| *Other* | 78 | 7.3 | 82.7 |
| *Pinch point action* | 51 | 4.8 | 87.5 |
| *Blind spot* | 44 | 4.1 | 91.6 |
| *Flying object action* | 33 | 3.1 | 94.7 |
| *Flammable liquid/solid exposure* | 30 | 2.8 | 97.6 |
| *Catch point/puncture action* | 26 | 2.4 | 100.0 |
| Total | 1065 | 100.0 | |

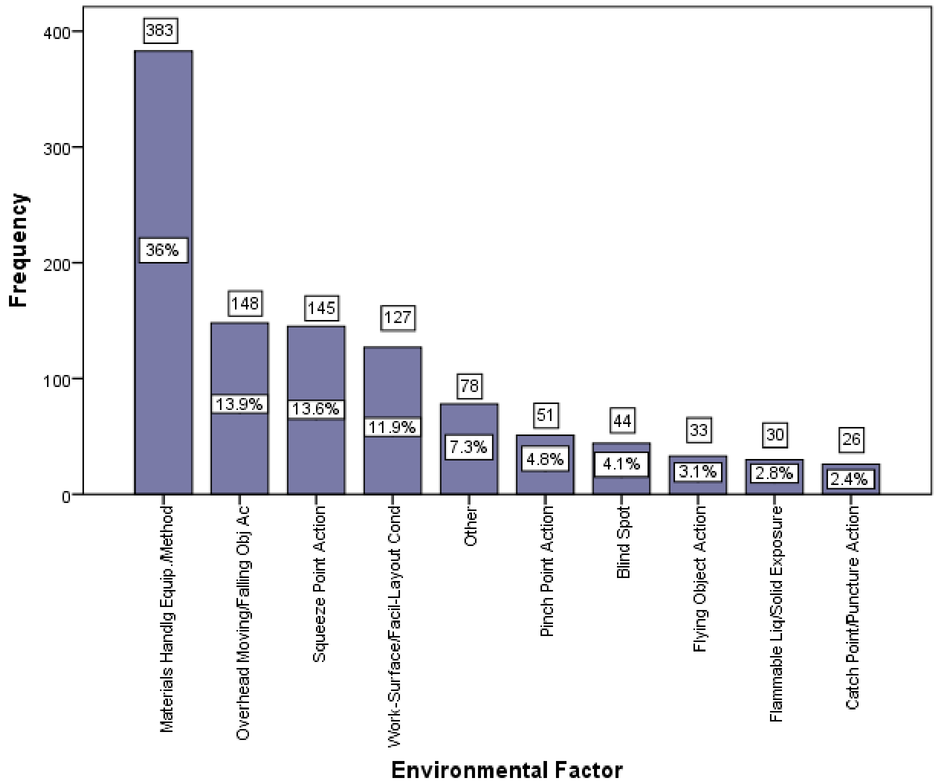


Figure 23: Frequency of environmental factor in accidents

It should be noted that the environmental factor category was unclear in most of the cases. OSHA assigns only a single factor as environmental factor whereas there can be more than one factor involved in some cases. When we consider the environment, one can easily assume that this coding is strictly related to the environment; however, some levels currently used by OSHA, such as pinch point action, squeeze point action, catch point/puncture action, and flammable liquid/solid exposure indicate a very broad view of the term. It should be further noted that this coding may also depend on the investigating OSHA compliance officer’s experience knowledge, training as well as judgment.

**4.1.4.7 Human factor**

Human factors are involved in virtually all accidents if it is assumed that all accidents are avoidable (Hinze et. al., 2005). OSHA tries to identify a single human factor that may have an effect on an accident. It is crucial to understand and gain knowledge of human factors, which can be "unsafe acts" that contribute to accident occurrence.

The results showed that 46.1% (491) of the cases involved misjudgment of hazardous situations. Inappropriate choice of/use of equipment/method for the job followed this with 19.2% (205). Inoperable/malfunctioned safety/warning devices also played a role in 14.9% (159) of the cases (Table 19). Further analysis was conducted on the misjudgment of hazardous situation cases in order to shed light on this issue. Results are presented later while covering crosstabulation analysis.

Table 19: Frequency of human factor in accidents

| | **Frequency** | **Percent** | **Cumulative Percent** |
|---|---|---|---|
| *Misjudgment of hazardous situation* | 491 | 46.1 | 46.1 |
| *Inappropriate choice/use of equipment/methods* | 205 | 19.2 | 65.4 |
| *Inoperable/malfunctioned safety/warning devices* | 159 | 14.9 | 80.3 |
| *Other* | 125 | 11.7 | 92.0 |
| *Insufficient engineering and admin control* | 57 | 5.4 | 97.4 |
| *Human system malfunction* | 21 | 2.0 | 99.3 |
| *Distracting actions by others* | 7 | .7 | 100.0 |
| Total | 1065 | 100.0 | |

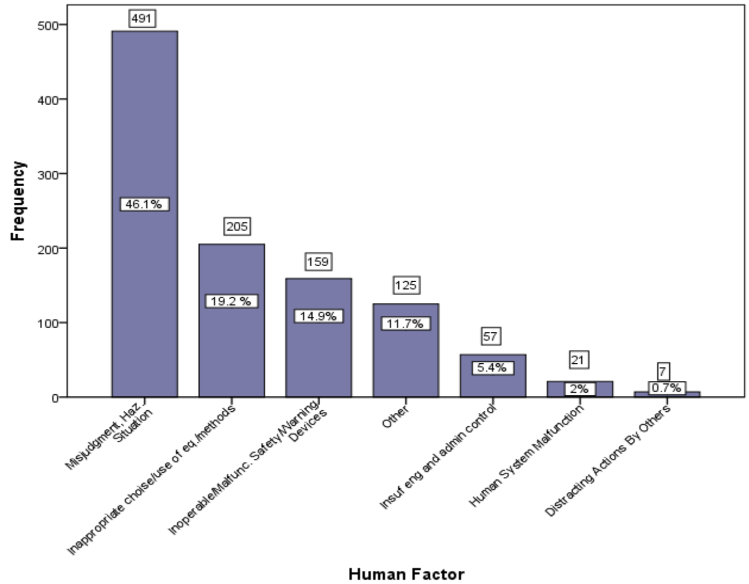


Figure 24: Frequency of human factor in accidents

### 4.1.4.8 Activity prompting accident

Among all cases, 193 occurred while pipe installation/trench excavation activity was being performed. As a close second, 184 cases were identified as site grading and rock removal. Lifting/rigging (165) and site clearing and grubbing (131) were other frequently observed levels of activities prompting accidents (Table 20).

Table 20: Frequency of activities prompting accidents

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Pipe installation/Trench excavation* | 193 | 18.1 | 18.1 |
| *Site grading and rock removal* | 184 | 17.3 | 35.4 |
| *Lifting/Rigging* | 165 | 15.5 | 50.9 |
| *Site clearing and grubbing* | 131 | 12.3 | 63.2 |
| *Loading/Unloading mat./equipment* | 100 | 9.4 | 72.6 |
| *Backfilling and compacting* | 73 | 6.9 | 79.4 |
| *Riding equipment/on Equipment* | 66 | 6.2 | 85.6 |
| *Equipment maintenance* | 65 | 6.1 | 91.7 |
| *Excavation other than trench* | 52 | 4.9 | 96.6 |
| *Demolition* | 36 | 3.4 | 100.0 |
| Total | 1065 | 100.0 | |

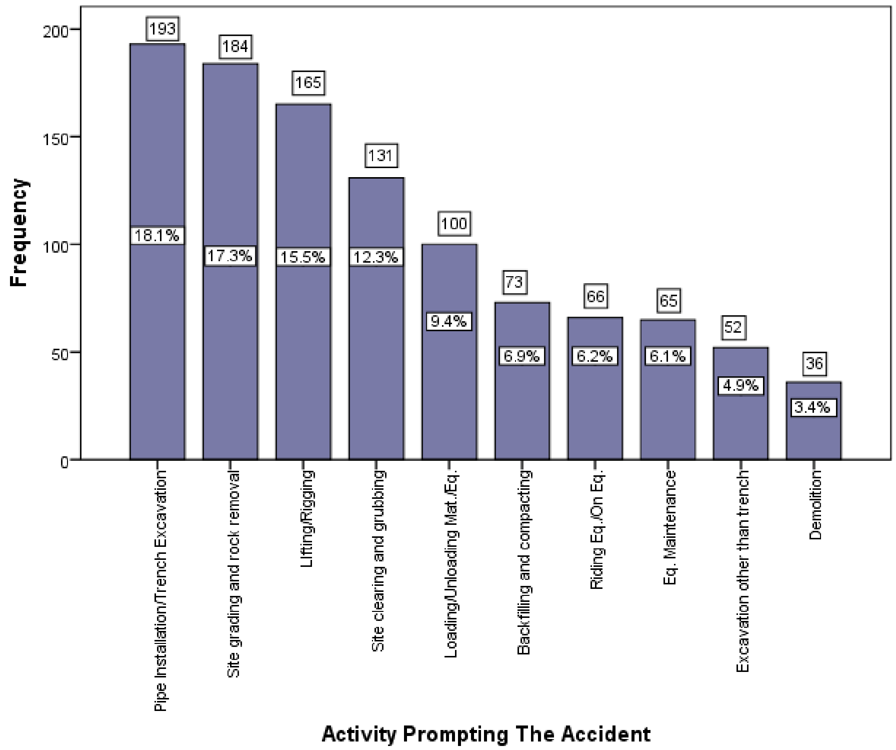


Figure 25: Frequency of activities prompting accidents

#### 4.1.4.9 Maintenance Issue

The researcher created the maintenance issue variable by studying the summary of the accident reports. If a summary mentions faulty brakes, hydraulics, broken glass, horns, inoperable back-up alarms, seat belts, weak chains etc. this was counted as there was a maintenance (inspection) problem with the equipment. As listed in Table 21, about 25% (24.4%) of the cases involved equipment with some type of maintenance (inspection) problem.

Table 21: Frequency of maintenance issue in accidents

| | **Frequency** | **Percent** | **Cumulative Percent** |
|---|---|---|---|
| *Not Present* | 805 | 75.6 | 75.6 |
| *Present* | 260 | 24.4 | 100.0 |
| Total | 1065 | 100.0 | |

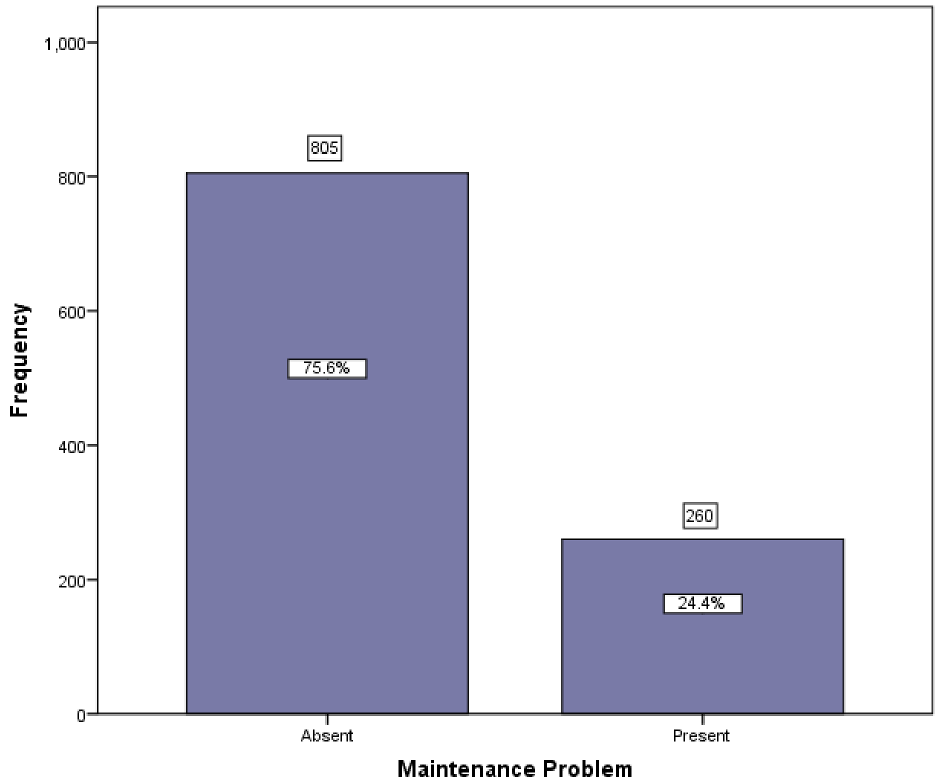


Figure 26: Frequency of maintenance problem in accidents

### 4.1.5 Worker Characteristics

#### 4.1.5.1 Standard industry classification (SIC) code

As discussed in the methodology section, only construction industry SIC codes were used for this particular study. Figure 27 shows that 24.7% of the cases were identified as SIC 1623. This industry code covers general and special trade contractors primarily engaged in the construction of water and sewer mains, pipelines, and communication and power lines. This is closely followed by SIC 1794, which covers special trade contractors primarily engaged in excavation work and digging foundations, including digging and loading. The next two SIC codes are 1629 (heavy construction, not elsewhere classified) and 1611 (highway and street construction, except elevated highways), with frequency counts of 146 and 144, respectively.

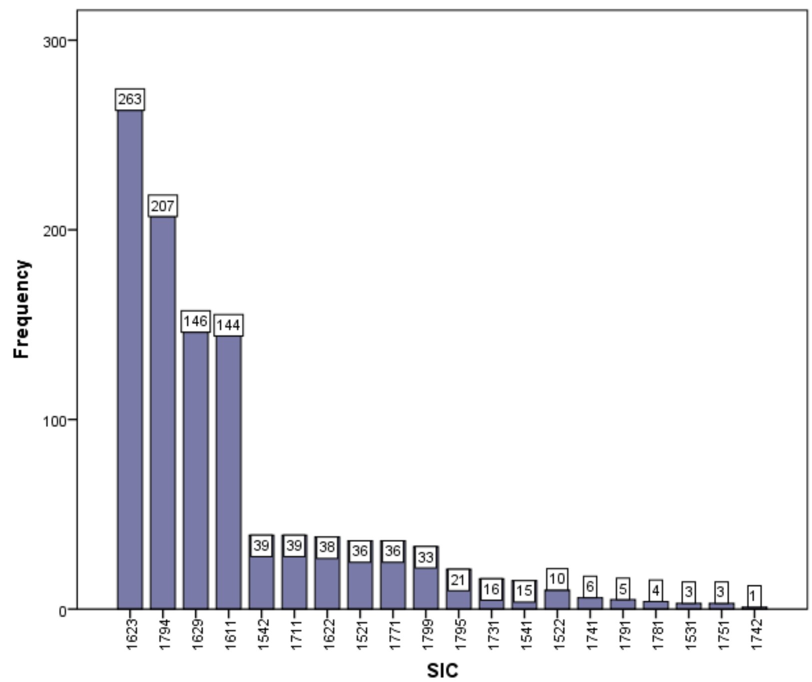


Figure 27: Frequency of standard industry classification among workers

#### 4.1.5.2 Task assignment regularity

Figure 28 and Table 22 show that a majority of accidents occurred while the victim was working on a regularly assigned task (88.7%). The common knowledge of inexperienced worker being more accident prone is not supported by this particular finding. This gives the idea that working on regularly assigned tasks may have given the victim more self-confidence. Thus, they may have disregarded safety precautions and become more accident prone. Further study was conducted in order to reveal more information on which human factors might affect workers when they work on regularly assigned tasks. Results are discussed in the next section covering crosstab analysis.

Table 22: Frequency of task assignment for workers

| | **Frequency** | **Percent** | **Cumulative Percent** |
|---|---|---|---|
| *Task regularly assigned* | 945 | 88.7 | 88.7 |
| *Task not regularly assigned* | 120 | 11.3 | 100.0 |
| Total | 1065 | 100.0 | |

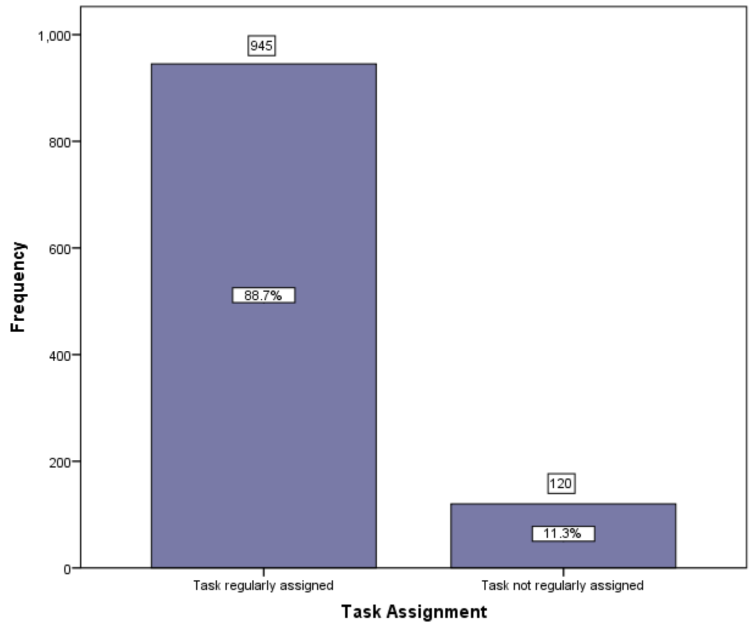


Figure 28: Frequency of task assignment for workers

#### 4.1.5.3 Gender

The construction industry is dominated by male workers. When gender was studied, results were as expected. Male victims were involved in 98.8% of the cases as seen in Table 23.

Table 23: Frequency of gender for workers

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Male* | 1052 | 98.8 | 98.8 |
| *Female* | 13 | 1.2 | 100.0 |
| Total | 1065 | 100.0 | |

#### 4.1.5.4 Union status

The results showed that 77.1 % of the victims were non-union workers, compared to 22.9% for union workers (Table 24). It is known that the number of union workers was significantly higher in the 1970's and earlier. However, the number of union workers has declined substantially since then. The higher labor cost of union workers, is another reason for this substantial decrease. This may explain the reason behind the big difference between two levels. However, further research was conducted to study whether being union or non-union plays a role in terms of safety. Results are presented in the next section covering logistic regression.

Table 24: Frequency of unionized and non-unionized workers

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| Non-Union | 821 | 77.1 | 77.1 |
| Union | 244 | 22.9 | 100.0 |
| Total | 1065 | 100.0 | |

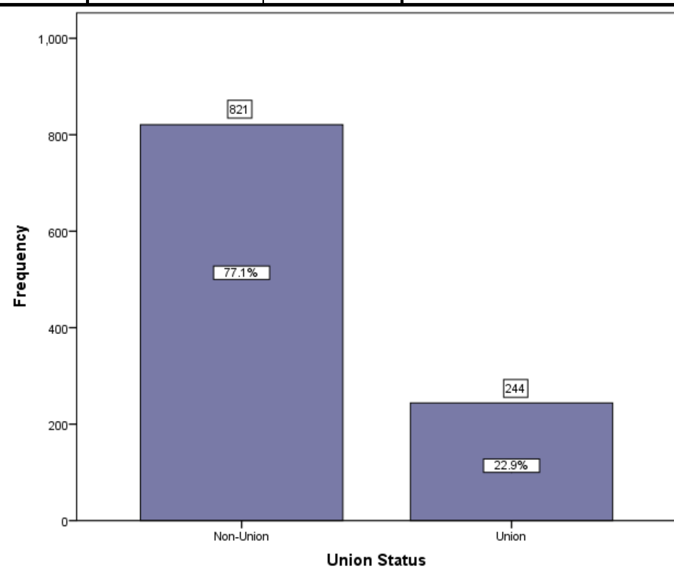


Figure 29: Frequency of unionized and non unionized workers

#### 4.1.5.5 Age

Age information was missing in 21 cases, which represents 2% of the cases. The univariate analysis performed on the data shows that the age group 35-39 is the most accident prone as can be seen from Figure 30.

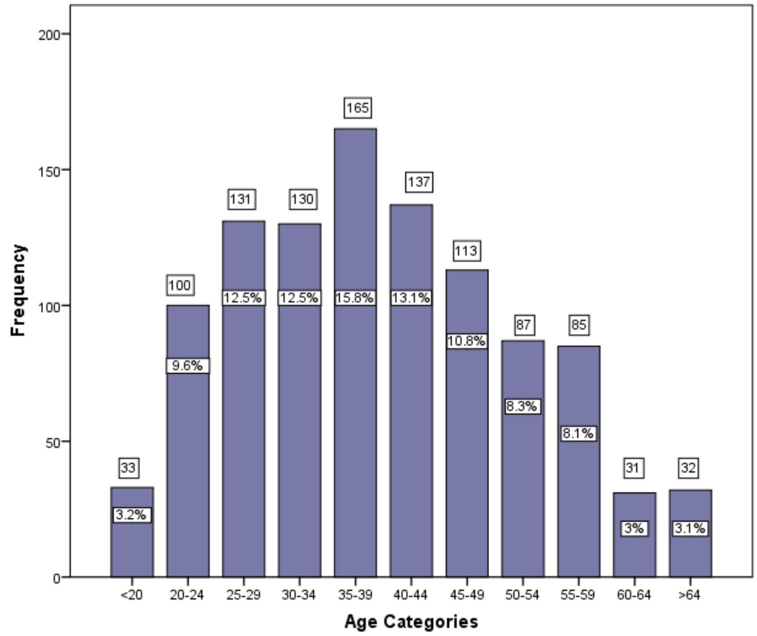


Figure 30: Frequency of age among workers

Table 25: Frequency of age among workers

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *<20* | 285 | 26.8 | 26.8 |
| *20-24* | 209 | 19.6 | 46.4 |
| *25-29* | 138 | 13.0 | 59.3 |
| *30-34* | 82 | 7.7 | 67.0 |
| *35-39* | 68 | 6.4 | 73.4 |
| *40-44* | 60 | 5.6 | 79.1 |
| *45-49* | 52 | 4.9 | 83.9 |
| *50-54* | 34 | 3.2 | 87.1 |
| *55-59* | 34 | 3.2 | 90.3 |
| *60-64* | 31 | 2.9 | 93.2 |
| *>64* | 25 | 2.3 | 95.6 |
| *Total* | 1044 | 98.0 | 100.0 |
| *Missing System* | 21 | 2.0 | |
| Total | 1065 | 100.0 | |

**4.1.5.6 Occupational function**

According to Table 26, 64.7% of the cases involved on-foot workers who work in close proximity to equipment on the construction site. On the other hand, cases involving operators represent 35.3% of the cases. It should be noted that operator vs on-foot worker categorization was made by case summaries. If an operator was involved in an accident when he was not in/on the equipment he was using, those cases were counted as an on-foot worker. Detailed research was conducted for two different occupational function types, and results are presented and discussed in the next section covering crosstabulation analysis.

Table 26: Frequency of occupational function

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *On-foot worker* | 689 | 64.7 | 64.7 |
| *Operator* | 376 | 35.3 | 100.0 |
| Total | 1065 | 100.0 | |

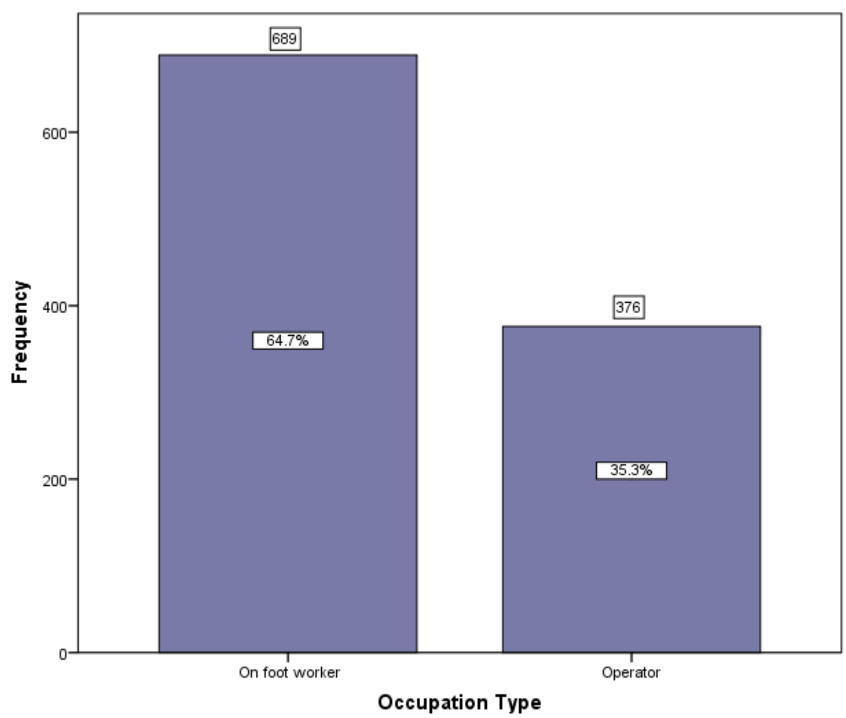


Figure 31: Frequency of occupational function

### 4.1.6 Safety Culture Characteristics

#### 4.1.6.1 Citation for Safety Program

OSHA citations were used to determine whether an adequate safety (accident prevention) program existed. According to the citations issued, 25.7% (274) of the cases were when a safety program which would have prevented the OSHA citation was not present or adequate enough. On the other hand, 74.3% (791) of the cases did not get any citation due to safety program (Table 27). This raises the question of whether the presence of a safety program by itself is enough to prevent accidents. Quality of the content, whether it is suitable for the project or not, and if it is used to enforce safety are some questions raised by this finding. It is quite clear that existence of a safety program alone by itself does not prevent accidents; however, the researcher also cannot come to a solid conclusion that safety programs are useless in terms of preventing accidents.

Table 27: Frequency of safety program

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Present* | 791 | 74.3 | 74.3 |
| *Not Present* | 274 | 25.7 | 100.0 |
| Total | 1065 | 100.0 | |

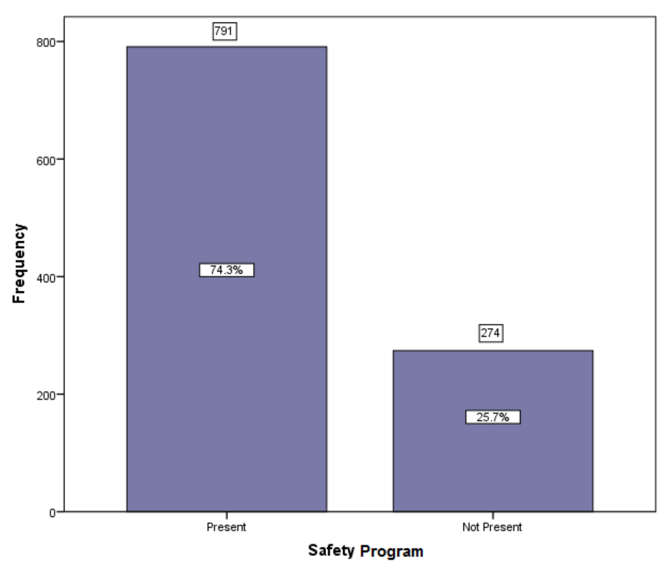


Figure 32: Frequency of safety program

**4.1.6.2 Citation for Safety Training**

As seen in Table 28, in 53.3% of the cases the victim had adequate safety training while 46.7% of the cases were identified as ones in which the victim did not have adequate or any safety training as determined by OSHA. Having such close numbers for both levels raises questions just like existence of a safety program. Content of the training, its suitability for the project, effectiveness, and whether it is up-to-date and tailored to particular task are important factors, and these cannot be identified or judged by only studying the case reports. However, interaction between safety training and human factors and some other related variables were further analyzed in this study by using crosstabulation and logistic regression methodology.  Findings are presented in the next section.

Table 28: Frequency of safety training

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Provided* | 568 | 53.3 | 53.3 |
| *Not Provided* | 497 | 46.7 | 100.0 |
| Total | 1065 | 100.0 | |

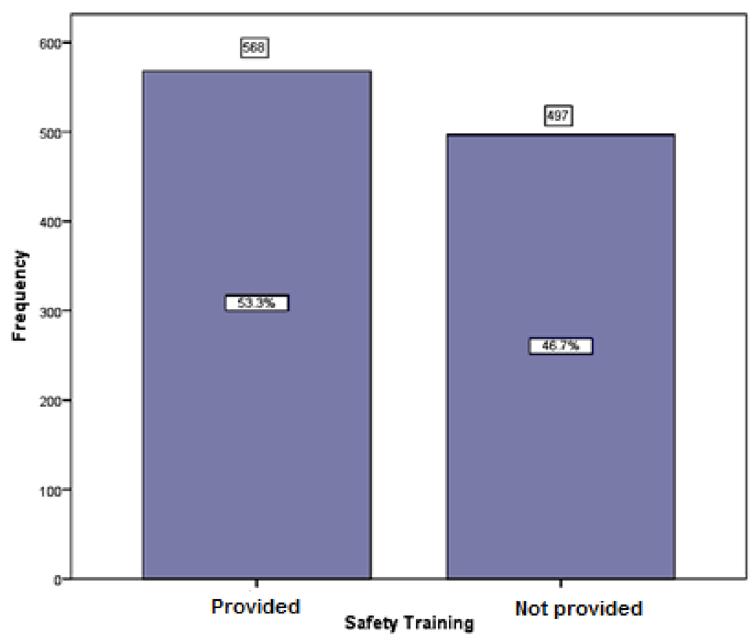


Figure 33: Frequency of safety training

**4.1.6.3 Citation for worker protective system usage**

According to Table 29, 242 of the cases had citation due to worker protective systems (e.g. ppe, seat belt) not used; in 823 of the cases the victim was using the appropriate protective systems. Further analysis was conducted to identify seat belt usage by operators and other protective equipment usage by on-foot workers. Results are presented in the following section.

Table 29: Frequency of protective system usage standard cited

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Used* | 823 | 77.3 | 77.3 |
| *Not used* | 242 | 22.7 | 100.0 |
| Total | 1065 | 100.0 | |

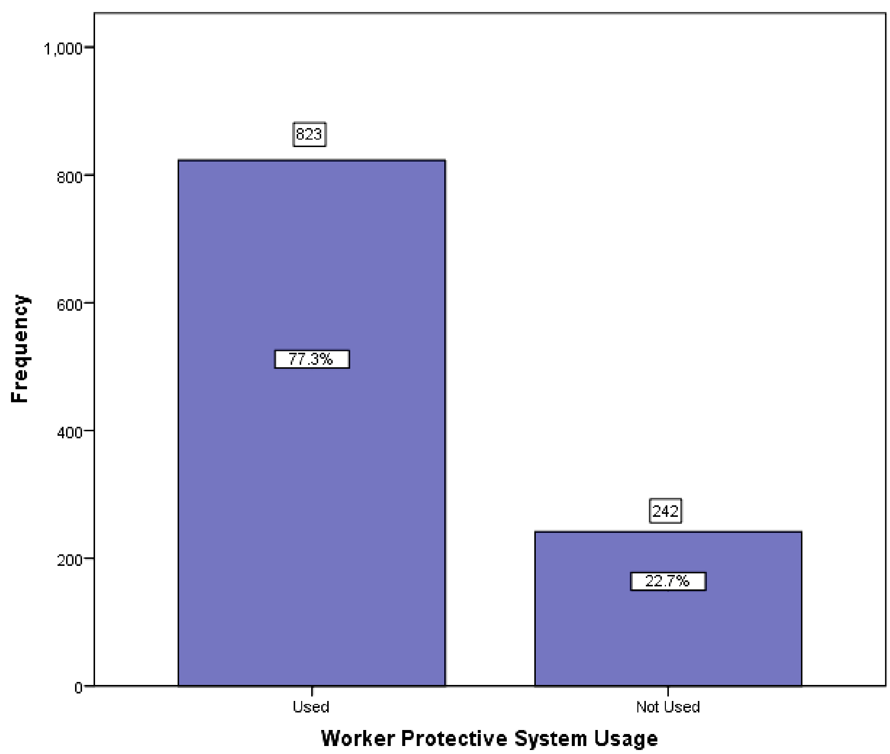


Figure 34: Frequency of protective system usage

#### 4.1.6.4 Citation for equipment protective systems presence

In reference to Table 30 and Figure 35, it was observed that only in 18.7% of the cases equipment were missing protective safety systems (e.g. brakes, bars, back-up alarm glass).

Table 30: Frequency of equipment protective system

| | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| *Present* | 866 | 81.3 | 81.3 |
| *Not present* | 199 | 18.7 | 100.0 |
| Total | 1065 | 100.0 | |

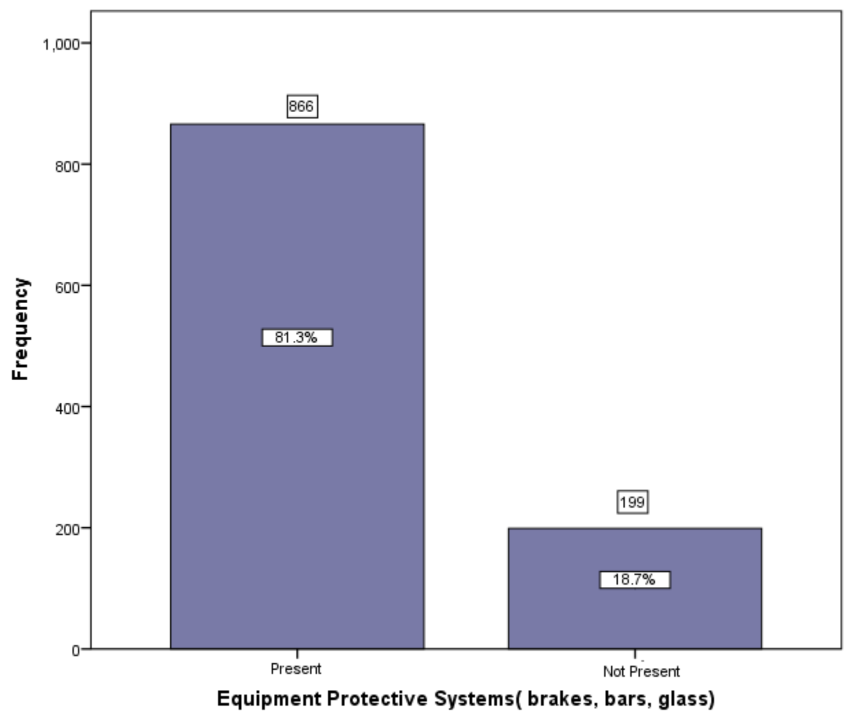


Figure 35: Frequency of equipment protective system

### 4.2 Crosstabulation Analysis Findings

In this section, contingency table (crosstabulation) analysis results of the accidents involving the heavy construction equipment (backhoe, excavator, grader and scraper) selected for fatal and nonfatal injury cases from the years 1982 to 2008 will be presented and discussed.

Univariate analysis gave us a general understanding of the whole dataset; however, it did not distinguish between the cases resulting in fatal injury or nonfatal injury. It also does not provide for bivariate analysis of any input factors.

The main highlights for the aggregate data analysis shaped the results section. Only significant findings are presented in a tabulated form.

It can be observed from Table 31 that among 1065 cases, 727 resulted in fatal accidents; operator fatalities are 27.2 % compared to on-foot workers with fatalities of 41%. When nonfatal injury frequencies were compared, it was revealed that operators are less susceptible for nonfatal injuries than on-foot workers; 86 cases were recorded as nonfatal injuries for operators, whereas this frequency was 252 for the on-foot workers. It was found that there is a significant association ($\chi^2(1)=21.081$ ,p=0.000) between occupational function and degree of injury. Crosstabulation analysis represents the fact that based on the odds ratio, equipment operators are **1.94** times more likely to be a victim of a fatal accident compared to on-foot workers.

Table 31: Degree of injury vs Occupational Function - Aggregate Data

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Occupational Function | *Operator* | 86 (8.1%) | 290(27.2%) | 376(35.3%) |
| | *On-foot worker* | 252 (23.7%) | 437(41.0%) | 689(64.7%) |
| Total | | 338(31.7%) | 727(68.3%) | 1065 |

| | | | |
|---|---|---|---|
| *Degree of Inj. Vs Occupation* | $\chi^2(1)=21.081$ ,p=0.000 | Crv(1)=0.139, p=0.000 | OR= 1.94 |

Figure 36 illustrates in graphical format how occupational function was distributed between levels of degree of injury.

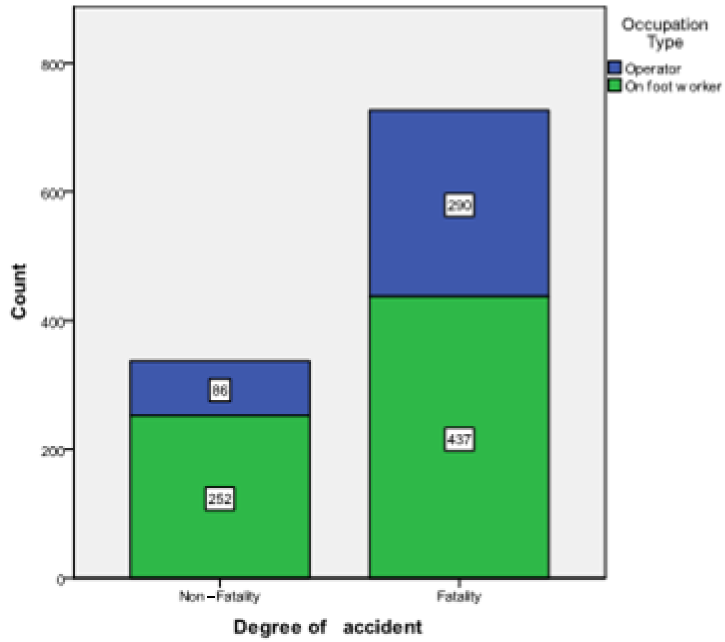


Figure 36: Crosstabulation graph of the degree of injury vs occupational function

Equipment type also is an important variable for the whole data set since this dissertation mainly focuses on four equipment types. Backhoe accidents are not only involved in the majority of the accidents, 507 which represents 47.6% of the cases, but also backhoes appeared to be the most deadly equipment with 331(31.1%) fatal injury counts (Table 32). Bulldozers and excavators accounted for 183 and 133 of the fatal accidents, respectively.

Table 32: Degree of injury vs Equipment Type – Aggregate Data

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Type | *Backhoe* | 176(16.5%) | 331(31.1%) | 507(47.6%) |
| | *Bulldozer* | 44(4.1%) | 183(17.2%) | 227(21.3%) |
| | *Excavator* | 91(8.5%) | 133(12.5%) | 224(21%) |
| | *Scraper* | 27(2.5%) | 80(7.5%) | 107(10%) |
| Total | | 338(31.7%) | 727(68.3%) | 1065 |

Compared to other equipment, the backhoe is used for a variety of tasks. It can be used as an excavator, or loader, and sometimes used like a crane to lift material. The backhoe size is also smaller than that of a bulldozer or excavator. Backhoes are mostly wheel-mounted instead of being on tracks, which gives them the ability to travel at higher speeds. All these characteristics make backhoes popular in every size of construction site. However, all these characteristics also create unique hazards according to the task it performs. Therefore, the one size fits all approach cannot be applied to the backhoes. Each activity needs to be carefully analyzed; associated hazards should be identified, and preventive measures should be taken by training its operator as well as on-foot workers on the site. Due to these unique characteristics, we developed a model for the backhoes by utilizing logistic regression analysis to predict accident severity. These results are discussed in the section on logistic regression findings.

In light of these findings, it was decided to individually analyze each victim by their occupation type. Furthermore, in order to identify the association between the variables and obtain the odds ratios, the results were divided into two sub levels and presented accordingly. The first section presents equipment operator involved accident analysis. Since statistical software is limited to providing the odds ratio for only the crosstabulation for 2x2, the findings are summarized in two separate tables, 2x2 and 2xk.

### 4.2.1 Crosstabulation results - Equipment operator cases

Table 33 summarizes the findings of degree of injury vs 2-level independent variables. It should be noted that statistically insignificant results have not been shown in the results.

Table 33: Croostabulation results for operators - degree of injury vs 2-level independent variables

| **Analyzed Variables** | **Pearson' s $\chi^2$(df), p** | **Phi & Cramer's V** | **Lambda** | **Odds Ratio** |
|---|---|---|---|---|
| **Degree of injury X** | 2 x 2 type | | | |
| *Seat Belt* | $\chi^2$(1)=5.126, p=0.024 | crv(1)=0.117, p=0.024 | 0 | 2.90 |
| *Union Status* | $\chi^2$(1)=12.616, p=0.000 | crv(1)=0.183, p=0.000 | 0 | 2.63 |
| *Safety Training* | $\chi^2$(1)=23.769, p=0.000 | crv(1)=0.251, p=0.000 | 0 | 3.731 |
| *Equipment Protective System* | $\chi^2$(1)=9.278, p=0.002 | crv(1)=0.157, p=0.002 | 0 | 2.898 |
| *Equipment Maintenance Issu.* | $\chi^2$(1)=5.036, p=0.025 | crv(1)=0.116, p=0.025 | 0 | 1.995 |

As one can see from Table 33, only 5 independent variables were identified as they are statistically associated with the degree of injury.

Seat belt existence makes a difference for only equipment operators, but not for on-foot workers. Therefore, this variable was only analyzed for the equipment operators. It showed a statistically significant association with degree of injury $\chi^2$(1)=5.126, p=0.024. Furthermore, this relationship, according to the scale introduced in the methodology section, is fairly weak. However, it is common knowledge that seat belts play an important role in the operators' safety. They are expected to help prevent injuries to heavy construction equipment operators during accidents. It appears that defective, inoperable or absent seat belt cases are low in number in the dataset. Only 13% (49) of the cases were identified as the seat belt was not present in the equipment (Table 34). Moreover, 44 of these accidents resulted in fatal injury. In contrast, 327 cases were identified as the seat belts present in the equipment, and 246 of these accidents resulted in a fatality. If we quantify this fact by the odds ratio, equipment operators riding identified specific earthmoving equipment with missing a seat belt are **2.9** times more likely to be the victim of a fatal accident compared to those with a seat belt present in the equipment.

However, having a seat belt in the equipment does not necessarily mean that it was used. Therefore, in order to investigate this even though PPE use was insignificant with degree of injury, we carried out a layered crosstabulation.

Table 34: Operator - Degree of injury vs Seat Belt Presence

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Seat Belt Presence | *Not Present* | 5(1.3%) | 44(11.7%) | 49(13%) |
| | *Present* | 81(21.6%) | 246(65.4%) | 327(87%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

Our layered crosstabulation analysis revealed that in 85 cases, seat belts were in place and operable; however, operators chose not to use them. Hence, 66 of these accidents resulted in fatalities. When the odds ratio was calculated for this layered crosstabulation (Table 35), it was found that not using seat belts when available, increases the odds fatal injury by **1.20** times for operators.

Table 35: Operator - Degree of injury vs Seat Belt Presence vs PPE Use

| | | | Degree of injury | | |
|---|---|---|---|---|---|
| *Seat Belt* | | | Nonfatal | Fatal | Total |
| *Present* | *PPE* | *Not Used* | *19(5.8%)* | *66(20.2%)* | *85(26%)* |
| | | *Used* | *62(19%)* | *180(55%)* | *242(74%)* |
| | *Total* | | *81(24.8%)* | *246(75.2%)* | *327* |
| | | | *22.9%* | *77.1%* | *100.0%* |

Union status is also a statistically significant associated ($\chi^2(1)=12.616$, $p=0.000$) variable when we analyze the operator cases about the degree of injury (Table 36). According to Cramer's V value (crv(1)=0.183) this association was shown to be in the weak association category.

When we studied the cell counts, about 80% of the cases involved non-union equipment operators whereas 20.2% of the victims were union operators. In further analysis, among the non- union workers the fatality frequency stood out and came out to be 81% (243) of 300 total non-union, in contrast to 19% of non-union cases that resulted in nonfatal injury. Based on these findings, further analysis about odds revealed that non-union operators are **<u>2.63</u>** times at greater risk of being involved in an accident resulting a fatal injury.

Table 36: Operator - Degree of injury vs Union Status

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Union Status | *Non-union* | 57(15.2%) | 243(64.6%) | 300(79.8%) |
| | *Union* | 29(7.7%) | 47(12.5%) | 76(20.2%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

The safety training variable is weakly associated with the degree of injury, and this association is statistically significant according to the Chi-square test and Cramer's V results ($\chi^2(1)=23.769$, $p=0.000$; crv(1)=0.251). When we checked the strength of the association, it was relatively stronger compared to other associated variables with the degree of injury. When the safety training variable was studied, as seen in Table 37, it was found that 174 cases were cited by OSHA because adequate safety training was not given to the operators. In 154 cases where operators were not properly trained, the accident resulted in fatal injuries. This finding revealed that equipment operators who were not trained according to the OSHA guidelines are **<u>3.74</u>** times more likely to be a victim of an accident resulting in fatality.

Table 37: Operator - Degree of injury vs Safety Training

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Safety Training | *Not Performed* | 20(5.3%) | 154(41%) | 174(46.3%) |
| | *Performed* | 66(17.6%) | 136(36.1%) | 202(53.7%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

Table 38 shows that in 90 cases equipment were either missing some type of protective system including but not limited to: brakes, rollover protection systems, hydraulic controllers, audible alarms, horns, or these components were not in adequately working condition. On the other hand, in 286 of the cases there were no problems with the equipment safety systems. Fatalities observed in 80 cases the equipment protective system not present. This observation is lower in contrast. When one looks at Table 38, it may be concluded that equipment protective systems increase the number of fatalities. At a glance this may sound true; however, when closely investigated and the odds ratio studied, it was revealed that the odds of an accident resulting in a fatality is increased **2.90** times when an operator drives equipment with missing safety systems. This also implies the significance of this study where the misinterpretation of results may occur by only looking at the univariate analysis results.

Table 38: Operator - Degree of injury vs Equipment Protective Systems

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Prtc. System | *Not Present* | 10(2.7%) | 80(21.2%) | 90(23.9%) |
| | *Present* | 76(20.2%) | 210(55.9%) | 286(76.1%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

OSHA suggests that before starting work, a brief maintenance check should be performed on the equipment. In 101 (26.9%) of the cases equipment maintenance was not performed, whereas in 275 cases such maintenance was performed (Table 39). In 86 of the cases, equipment had a maintenance issue and resulted in fatalities. In contrast, the related case number and frequency is 204.

When equipment maintenance is not performed, this may lead to use equipment with missing or inoperable safety protective systems for operators as well as on-foot workers. Also, failing to maintain equipment properly may lead to the breakdown of attachments, hooks, chains, etc. during performed work, which jeopardizes workers' lives. Therefore, equipment maintenance is an important factor for operators as well as for on-foot workers. The odds ratio analysis showed that operators who use inadequately maintained equipment are **1.995** times more at risk to be involved in a fatal accident compared to operators who use adequately maintained equipment.

Table 39: Operator - Degree of injury vs Equipment Maintenance

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Maintenance | *Not Performed* | 15(4%) | 86(22.9%) | 101(26.9%) |
| | *Performed* | 71(18.9%) | 204(54.2%) | 275(73.1%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

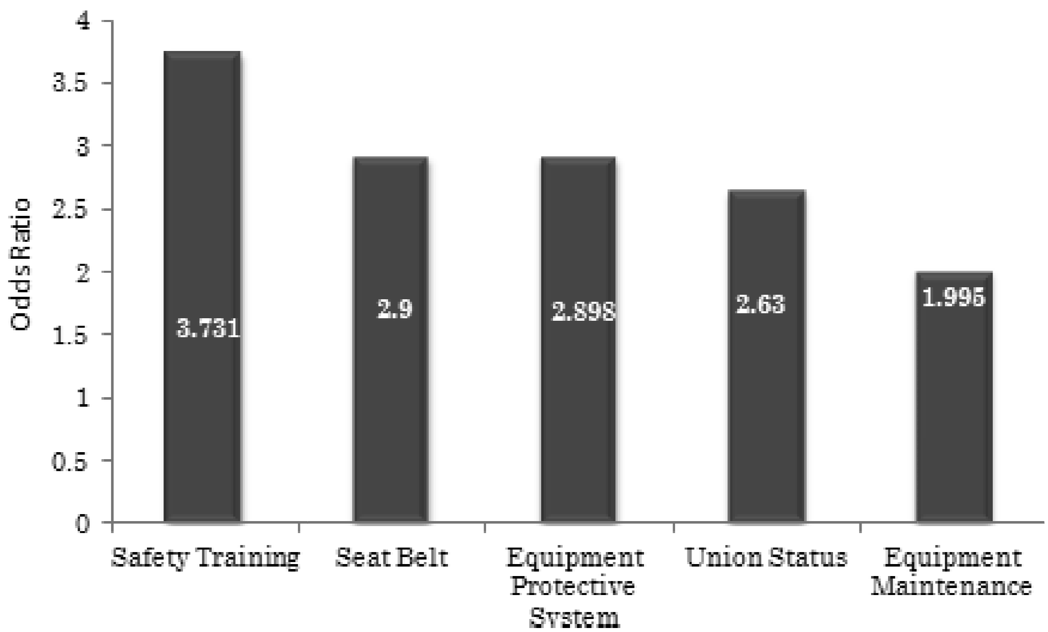


Figure 37: Operator - Odds ratios for variables associated with degree of injury

Based on the findings presented earlier, Figure 37 demonstrates the graphical comparisons odds ratios for the statistically significant variables which showed association with the degree of injury for operators. Absence of adequate safety training increases the odds of fatal injuries the most compared to other variables; therefore, this can be interpreted as OSHA safety training standards should be strictly enforced. Safety training variable was followed by other fatal injury odds increasing variables such as seat belt absence, equipment protective system absence, non-union status and equipment maintenance absence and the multiplier varies between 2 and 3.

Table 40 below summarizes the crosstabulation results of the degree of injury vs k-level independent variables.

Table 40: Crosstabulation results for operators - degree of injury vs k-level independent variables

| **Analyzed Variables** | **Pearson' s $\chi^2$(df), p** | **Phi & Cramer's V** | **Lambda** |
|---|---|---|---|
| **Degree of injury X** | 2 X k type | | |
| *SIC* | $\chi^2$(4)=13.910, p=0.008 | crv(4)=0.192, p=0.008 | 0 |
| *Equipment Type* | $\chi^2$(3)=9.232, p=0.026 | crv(3)=0.157, p=0.026 | 0 |
| *Event Type* | $\chi^2$(4)=42.806, p=0.000 | crv(4)=0.337, p=0.000 | 0.093 |
| *Environmental Factor* | $\chi^2$(9)=24.724, p=0.003 | crv(9)=0.256, p=0.003 | 0.035 |
| *Human Factor* | $\chi^2$(6)=14.010, p=0.03 | crv(6)=0.193, p=0.03 | 0.012 |
| *AGE* | $\chi^2$(10)=18.631, p=0.045 | crv(10)=0.224, p=0.045 | 0 |

Frequency values and percentages of fatal/nonfatal injury cases for operators according to their SIC (Standard Industrial Classification) are tabulated in Table 41. The Chi-square test for this variable showed a statistically significant association ($\chi^2$(4)=13.910, p=0.008). This association is fairly weak according to the Cramer's V value (crv(4)=0.192). The dataset includes operators from nearly all coded industries; however, SIC code 1623 (water, sewer, pipeline, communication & power line construction), 1794 (excavation work), 1629 (heavy construction) and 1611(highway and street construction) shows relatively high frequencies compared to others (which were grouped under the "other" category) due to their small frequencies.

Table 41: Operator - Degree of injury vs SIC

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| SIC Code | *1623* | 17(4.5%) | 32(8.5%) | 49(13%) |
| | *1794* | 24(6.4%) | 57(15.2%) | 81(21.5%) |
| | *1629* | 9(2.4%) | 73(19.4%) | 82(21.8%) |
| | *1611* | 9(2.4%) | 45(12%) | 54(14.4%) |
| | *Other* | 27(7.2%) | 83(22.1%) | 110(29.3%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

Equipment type is another variable found to have statistically significant association with degree of injury ($\chi^2(4)$=42.806, p=0.000 and crv(3)=0.157). In Table 42, crosstabulation analysis reveals that backhoes and bulldozer ares more dangerous equipment types for operators compared to excavators and scrapers. About 70% of the accidents involved backhoes or bulldozers (37.2% and 35.1%, respectively) and these equipment were responsible for 58.3% of the fatalities. Backhoes in 109 cases and bulldozers in 110 cases injured their operators fatally.

When the dummy coding method was applied to the equipment type variable in order to quantify the risk by calculating the odds ratio, it was revealed that being an operator on a backhoe increases the fatal injury odds by 1.06 times compared to other equipment; yet, with the same technique, bulldozer operators are 1.778 times more in danger of fatality in an accident than other equipment operators. Being the operator of the other equipment, excavators and scrapers, decreases the fatal injury risk by 0.221 and 0.564 times, respectively.

Therefore, it was concluded that bulldozers are the most deadly equipment for the operators. This is attributed to the work they perform being relatively different than other equipment studied. Bulldozers are more susceptible to rollover accidents due to their job being on uneven surfaces, such as when operators come too close to an edge or ditch and slide the equipment down the edge, causing rollover accident. When this happens, the bulldozer puts the operator in danger of becoming pinned or crushed under the massive weight of the machine or under its rollover protective structure especially when seat belt is not used during operation of the equipment.

Table 42: Operator - Degree of injury vs Equipment Type

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Type | *Backhoe* | 31(8.2%) | 109(29%) | 140(37.2%) |
| | *Bulldozer* | 22(5.9%) | 110(29.3%) | 132(35.1%) |
| | *Excavator* | 15(4%) | 41(10.9%) | 56(14.9%) |
| | *Scraper* | 18(4.8%) | 30(8%) | 48(12.8%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

According to Chi-square test results, event type had a statistically significant association with the degree of injury, but this association was weak according to the adopted Cramer's V scale ($\chi^2(4)=42.806$, $p=0.000$; crv(4)=0.337). However, it should be noted that when this Cramer's V value is compared to those of other significant variables, this association is stronger. As seen in Table 43, operators were victims in accidents involving struck-by and caught in/or between events. These levels together represent 76% of the cases where operators were involved. Struck-by events were responsible for 132 fatal accidents and caught in/or between event type accounted for 115 fatal accidents.

When struck-by events were further analyzed, it was revealed that 114(72.2%) of these events were identified as being struck by an equipment, which are mostly due to rollover and overturning accidents when the operator in/on a vehicle collides with a part of the equipment (e.g the canopy). This was followed by being struck by a falling object, accounting for 28 (17.7%) of the cases. The remainder of the events occurred due to being struck by attachments, struck by falling attachments and struck by swinging/flying objects, accounting for 10% of the remaining cases.

Table 43: Operator - Degree of injury vs Event Type

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Event Type | *Caught in or between* | 13(3.4%) | 115(30.6%) | 128(34%) |
| | *Electrocution* | 7(1.9%) | 9(2.4%) | 16(4.3%) |
| | *Fall from elevation* | 17(4.5%) | 9(2.4%) | 26(6.9%) |
| | *Other* | 13(3.5%) | 35(9.3%) | 48(12.8%) |
| | *Struck-by* | 36(9.6%) | 122(32.4%) | 158(42%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

The environmental factor variable is weakly associated with the degree of injury, and this association is statistically significant according to the Chi-square test and Cramer's V results ($\chi^2(9)=24.724$, $p=0.003$; crv(9)=0.256). Table 44 presents the frequency distribution of the environmental factors crossed with the degree of injury. The "materials handling equipment/method" shows the highest count with 129, followed by the "work-surface/facility-layout condition", which covers 78 cases for operators. Also, the same levels show higher fatal case frequencies; 100 and 58, respectively. Therefore, using the right equipment for the job, being familiar with the layout of the work-surface/facility and the associated hazards would decrease the number of fatalities among the operators. Extra attention should be given to safe work practices had been operators use their equipment when these conditions prevail.

Table 44: Operator - Degree of injury vs Environmental Factors

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Env. Factor | *Blind Spot* | 1(.3%) | 0(0%) | 1(.3%) |
| | *Catch point/puncture action* | 1(.3%) | 8(2.1%) | 9(2.4%) |
| | *Flammable liq./solid exposure* | 5(1.3%) | 8(2.1%) | 13(3.5%) |
| | *Flying object action* | 6(1.6%) | 4(1.1%) | 10(2.7%) |
| | *Materials handling equip./method* | 29(7.7%) | 100(26.6%) | 129(34.3%) |
| | *Overhead moving/falling object action* | 5(1.3%) | 31(8.2%) | 36(9.6%) |
| | *Pinch point action* | 3(.8%) | 12(3.2%) | 15(4%) |
| | *Squeeze point action* | 2(.5%) | 38(10.1%) | 40(10.6%) |
| | *Work-surface/facility-layout condition* | 20(5.3%) | 58(15.4%) | 78(20.7%) |
| | *Other* | 14(3.7%) | 31(8.2%) | 45(11.9%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

There is a weak statistically significant association between human factor and degree of injury ($\chi^2(6)=14.010$, $p=0.03$; $crv(6)=0.193$). Table 45 clearly shows that misjudgment of hazardous situations (52.7%) and inappropriate choice/use of equipment/methods are the highest frequency human factors involved in operator accidents. Misjudgment of hazardous situations was also responsible for 159 (42.3%) cases, resulting in fatality.

Table 45: Operator - Degree of injury vs Human Factors

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Human Factor | *Distracting actions by others* | 1(.3%) | 0(0%) | 1(.3%) |
| | *Human system malfunction* | 4(1%) | 7(1.9%) | 11(2.9%) |
| | *Inappropriate choice/use of eq./methods* | 9(2.4%) | 46(12.2%) | 55(14.6%) |
| | *Inoperable/malfunctioned safety/warningdevices* | 14(3.7%) | 35(9.3%) | 49(13%) |
| | *Insufficient eng. and admin controls* | 2(.5%) | 14(3.7%) | 16(4.3%) |
| | *Misjudgment of hazardous situation* | 39(10.4%) | 159(42.3%) | 198(52.7%) |
| | *Other* | 17(4.5%) | 29(7.7%) | 46(12.2%) |
| Total | | 86(22.9%) | 290(77.1%) | 376 |

We conducted a detailed analysis of the misjudgment of hazardous situations versus selected variables, such as task assignment regularity, and questioned if this shows a type of pattern with misjudgment. In 338 cases operators were assigned to their regular tasks when they misjudged the hazardous situation. Further analysis is necessary to reveal the cause of these human factors. One aspect to investigate is whether safety training has any corrective effect on the misjudgment of hazardous situations or to prevent the inappropriate choice/use of equipment/methods. Further research is necessary to enlighten these human factors in detail and offer remedial measures.

With the Chi-square value $\chi^2(10)=18.631$, $p=0.045$ and crv(10)=0.224, the age variable is in a weak statistically significant association with the degree of injury. The average age of equipment operators who got injured in an earthmoving equipment related accident was found to be 41.75 between the years 1983 and 2008. Equipment operators between the ages of 40 and 44 appeared slightly more accident prone (14.6%) compared to other age levels. (Table 46) Also, the same age group was found to be little more fatal injury susceptible.10.9% of the cases were observed in this age group. This group was closely followed by the 35-39 and 45-49 age groups. Their fatal injury case frequencies were 10% and 10.5% of the total cases, respectively.

Table 46: Operator - Degree of injury vs Age

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Age | *<20* | 1(.3%) | 2(.5%) | 3(.8%) |
| | *20-24* | 5(1.3%) | 23(6.2%) | 28(7.5%) |
| | *25-29* | 8(2.2%) | 33(8.9%) | 41(11.1%) |
| | *30-34* | 19(5.1%) | 24(6.5%) | 43(11.6%) |
| | *35-39* | 14(3.7%) | 37(10%) | 51(13.7%) |
| | *40-44* | 14(3.7%) | 40(10.9%) | 54(14.6%) |
| | *45-49* | 7(1.9%) | 39(10.5%) | 46(12.4%) |
| | *50-54* | 5(1.4%) | 26(7%) | 31(8.4%) |
| | *55-59.* | 10(2.7%) | 38(10.2%) | 48(12.9%) |
| | *60-64* | 1(.3%) | 11(2.9%) | 12(3.2%) |
| | *>64* | 1(.3%) | 13(3.5%) | 14(3.8%) |
| Total | | 85(22.9%) | 286(77.1%) | 371 |

### 4.2.2 Crosstabulation results - On-foot worker cases

Table 47 summarizes the findings of degree of injury vs 2-level independent variables for the on-foot workers.

Table 47: Crosstabulation results for on-foot workers - degree of injury vs 2-level independent variables

| **Analyzed Variables** | **Pearson' s $\chi^2$ (df), p** | **Phi & Cramer's V** | **Lambda** | **Odds Ratio** |
|---|---|---|---|---|
| **Degree of injury X** | 2 x 2 type | | | |
| *Equipment Back-up Motion* | $\chi^2$(1)=10.139, p=0.001 | crv(1)=0.121, p=0.001 | 0 | 1.945 |
| *Eq. Back-up Alarm Condition* | $\chi^2$(1)=10.396, p=0.001 | crv(1)=0.123, p=0.001 | 0 | 2.7 |
| *Union Status* | $\chi^2$(1)=18.827, p=0.000 | crv(1)=0.165, p=0.000 | 0 | 2.17 |
| *Safety Program* | $\chi^2$(1)=4.198, p=0.040 | crv(1)=0.078, p=0.040 | 0 | 1.45 |
| *Safety Training* | $\chi^2$(1)=27.587, p=0.000 | crv(1)=0.200, p=0.000 | 0 | 2.35 |
| *Equipment Protective System* | $\chi^2$(1)=7.778, p=0.005 | crv(1)=0.106, p=0.005 | 0 | 1.92 |

Table 48: On-foot workers - Degree of injury vs Equipment Back-up Motion

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Back Up Motion | *Not Present* | 216(31.4%) | 330(47.9%) | 546(79.3%) |
| | *Present* | 36(5.2%) | 107(15.5%) | 143(20.7%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

P-value was found to be significant for equipment back-up motion, indicating that there is an association between the variables ($\chi^2(1)=10.139$, $p=0.001$). According to Cramer's V value (crv(1)=0.121) this association is weak. Table 48 shows that 20.7% of the cases occurred when the equipment was traveling in the reverse direction and 107 of these accidents resulted in fatalities. Nonfatal injury frequency was fairly less (5.2%) when equipment is involved in accidents during back-up state.

An on-foot worker is **1.95** times more likely to be involved in a fatal accident when equipment is in back-up motion. This finding not only supports other researchers' (Hinze and Teizer, 2011; McCann, 2006) findings but also quantifies the risk with the back-up motion in terms of degree of injury.

We carried out our analysis a step further and conducted a layered cross tabulation analysis between degree of injury, back-up motion and equipment type. Table 49 presents the findings of this analysis. It was revealed that backhoes and bulldozers were responsible for 60.9% of the back-up accidents combined. This layer analysis shows that backing up bulldozers caused 35 fatal accidents; whereas backhoes 33, scrapers 29, and excavators 10 while on-foot workers were working around them.

When the dummy coding method was applied to calculate the odds ratio for each equipment, the following results were found. Reversing backhoes increased the odds of fatal injury **1.16** times compare to others. When bulldozers were investigated, bulldozers, in back-up motion, increased the odds of fatality **1.46** times for the on-foot workers. Scrapers were found to be more dangerous in terms of increasing odds. When a backing scraper is involved in an accident, it is **1.89** times more likely to result in a fatality. An excavator's back-up motion does not increase the odds of fatal injury for the on-foot workers.

Table 49: Degree of injury vs Equipment Type vs Back-up Motion

| Back Up Motion | | | Degree of injury | | |
|---|---|---|---|---|---|
| | | | Nonfatal | Fatal | Total |
| Present | Equipment Type | *Backhoe* | 10(7%) | 33(23.1%) | 43(30.1%) |
| | | *Bulldozer* | 9(6.3%) | 35(24.5%) | 44(30.8%) |
| | | *Excavator* | 11(7.7%) | 10(7%) | 21(14.7%) |
| | | *Scraper* | 6(4.2%) | 29(20.3%) | 35(24.5%) |
| Total | | | 36(25.2%) | 107(74.8%) | 143 |

When the association between back-up alarm and degree of injury was questioned, it was revealed that there is a weak statistically significant association between two ($\chi^2(1)=10.396$, $p=0.001$; crv(1)=0.123). According to Table 50, 10% (69) of the on-foot worker cases were identified as involving equipment that did not have working back-up alarms (audible alarms). 56 of these accidents resulted in fatalities. Only 13 cases resulted in nonfatal injuries when the back-up alarm was not working.

Table 50: On-foot workers - Degree of injury vs Back-up Alarm Condition

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Back-up Alarm Condition | *Not Working* | 13(1.9%) | 56(8.1%) | 69(10%) |
| | *Working* | 239(34.7%) | 381(55.3%) | 620(90%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Not having a back-up alarm warning system on equipment increases the odds of fatal injury by **2.7** compared to equipment with a working back-up alarm. When this finding is analyzed together with back-up motion involvement results, it was found that in 83 cases, even though the back-up alarm was working while equipment was backing up, it was not helpful in alerting on-foot workers in the vicinity of the danger zone. It is possible that multiple back-up alarm signals from (multiple) vehicles sending warning signals at the same time may have influenced workers' judgment, making the signal(s) less effective. Therefore, in these 83 cases, it is likely that the job site noise level has played a role in drowning out back-up alarms.

Table 51: Degree of injury vs Back-up Alarm Condition vs Back-up Motion

| Back Up Motion | | | Degree of injury: Nonfatal | Fatal | Total |
|---|---|---|---|---|---|
| Present | Back Up Alarm Condition | *Not Working* | 12(8.4%) | 48(33.6%) | 60(42%) |
| | | *Working* | 24(16.8%) | 59(41.3%) | 83(58%) |
| | | | 36(25.2%) | 107(74.8%) | 143 |

According to the findings presented in Table 52, a majority (75.6%) of the on-foot workers were not union members, whereas only 24.4% were identified as unionized. The Chi-square test revealed that ($\chi^2(1)$=18.827, p=0.000; crv(1)=0.165) there is a statistically significant association between union status and degree of injury.

Table 52: On-foot workers - Degree of injury vs Union Status

| | | Degree of injury: Nonfatal | Fatal | Total |
|---|---|---|---|---|
| Union Status | *Non-union* | 167(24.2%) | 354(51.4%) | 521(75.6%) |
| | *Union* | 85(12.4%) | 83(12%) | 168(24.4%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Also, cross tabulation analysis revealed that being a non-union worker increased the odds of fatal injury by **2.17** compared to being a union worker. According to an OSHA Economic News Release titled "Union Members Summary", only 13.2% of the workers in the construction industry were classified as unionized workers in 2012 (http://www.bls.gov/ news.release/union2.nr0.htm). Also, another study published by the Construction Labor Research Council underlined that the number of union workers were significantly higher in the 1970's and earlier (http://www.clrcconsulting.org/ samples/ Union-Nonunion Trends-2011.pdf). This may be the underlying result of the big difference between union and non-union worker cases; also as discussed earlier, high labor cost of union workers may make job owners prefer non-union workers.

Table 53: On-foot workers - Degree of injury vs Safety Program

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Safety Program | *Not Present* | 60(8.7%) | 136(19.7%) | 196(28.4%) |
| | *Present* | 192(27.9%) | 301(43.7%) | 493(71.6%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Safety program (Table 53) citation is one of the variables that is statistically significantly associated with the degree of injury ($\chi^2(1)=4.198$, $p=0.04$; crv(1)=0.078). Out of 689 cases in the dataset, 28.4% (136) were cited by OSHA due to not having any or inadequate safety programs after investigation. This reveals the odds as follows: the lack of an adequate safety program increases the odds of fatal injury by **1.45** times compared to the presence of such a safety program.

When the safety training variable was studied (Table 54), it was found that there is a statistically significant association between safety training and the degree of injury ($\chi^2(1)=27.587$, $p=0.00$; crv(1)=0.200). Even though this association is weak according to Cramer's V value, this value is the highest among the other significant values for the on-foot workers. Also, crosstabulation analysis underlined that 323 cases were cited by OSHA due to inadequate safety training of the on-foot workers, and more fatalities occurred (238) when on-foot workers were not trained. This finding revealed that on-foot workers who were not trained according to the OSHA guidelines are **2.35** times more likely to be a victim of an accident resulting in a fatality.

Table 54: On-foot workers - Degree of injury vs Safety Training

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Safety Training | *Not Performed* | 85(12.4%) | 238(34.5%) | 323(46.9%) |
| | *Performed* | 167(24.2%) | 199(28.9%) | 366(53.1%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Equipment protective system presence on equipment is an important factor for on-foot workers' safety. This includes but is not limited to breaks, back-up warning sound devices, etc. In 109 (15.9%) of the cases, equipment involved in accidents were missing such safety systems; furthermore, 82 of these accidents resulted in fatalities. When odds ratio was studied, it was found that the absence of an equipment protective system increases the odds of fatal injury by **1.92** times compared to when such protective system is present.

Table 55: On-foot workers - Degree of injury vs Equipment Protective Systems

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Protective Sys. | *Not Present* | 27(3.9%) | 82(11.9%) | 109(15.8%) |
| | *Present* | 225(32.7%) | 355(51.5%) | 580(84.2%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Based on the findings presented earlier, Figure 38 summarizes and compares the odds ratios for the statistically significant variables, which showed significant association with the degree of injury for the on-foot workers. It is clear that the odds of fatal injury is the highest when equipment is not equipped with back-up alarms or equip with an inoperable back-up alarm for on-foot workers compared to other significant variables.

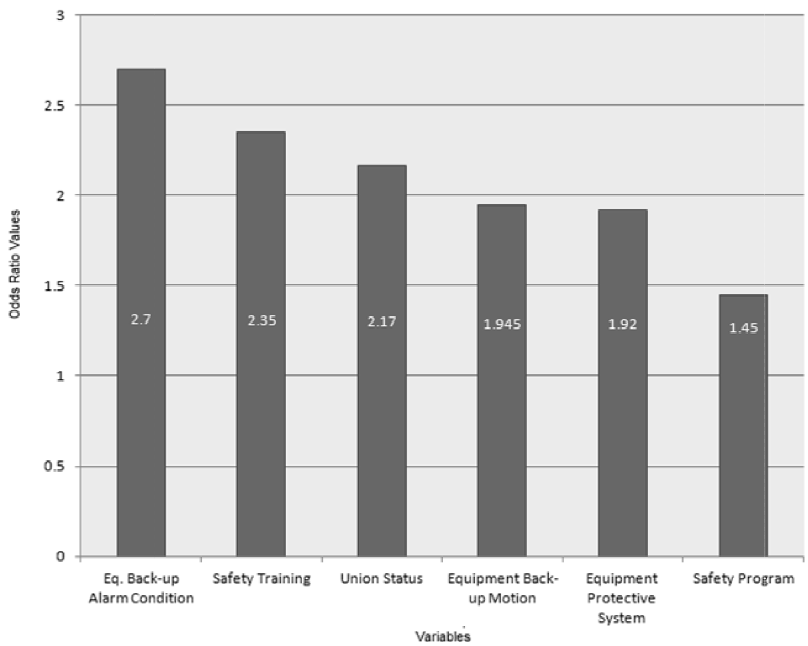


Figure 38: Odds ratio – Variables associated with the degree of injury

The final step for crosstabulation analysis was analyzing the degree of injury with k-level independent variables for the on-foot workers. As it is summarized in Table 56 most of the variables have an association with the dependent variable (degree of injury).

Table 56: Crosstabulation results for on-foot workers - degree of injury vs k-level independent variables

| **Analyzed Variables** | **Pearson' s $\chi^2$ (df), p** | **Phi & Cramer's V** | **Lambda** |
|---|---|---|---|
| **Degree of injury X** | 2 X k type | | |
| *Months* | $\chi^2$(11)=24.488, p=0.011 | crv(11)=0.189, p=0.011 | 0 |
| *Equipment Type* | $\chi^2$(3)=25.731, p=0.000 | crv(3)=0.193, p=0.000 | 0 |
| *Equipment Involvement* | $\chi^2$(2)=26.822, p=0.000 | crv(2)=0.197, p=0.000 | 0 |
| *Event Type* | $\chi^2$(4)=16.503, p=0.002 | crv(4)=0.155, p=0.002 | 0.048 |
| *Environmental Factor* | $\chi^2$(9)=22.820, p=0.007 | crv(9)=0.182, p=0.007 | 0.036 |
| *Human Factor* | $\chi^2$(6)=13.196, p=0.040 | crv(6)=0.138, p=0.040 | 0.008 |
| *AGE* | $\chi^2$(10)=35.960, p=0.000 | crv(10)=0.231, p=0.000 | 0.008 |

Table 57: On-foot workers - Degree of injury vs Months

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Months | *January* | 14(2%) | 26(3.8%) | 40(5.8%) |
| | *February* | 9(1.3%) | 41(6%) | 50(7.3%) |
| | *March* | 13(1.9%) | 40(5.8%) | 53(7.7%) |
| | *April* | 27(3.9%) | 33(4.8%) | 60(8.7%) |
| | *May* | 14(2.1%) | 34(4.9%) | 48(7%) |
| | *June* | 30(4.3%) | 44(6.4%) | 74(10.7%) |
| | *July* | 22(3.2%) | 35(5.1%) | 57(8.3%) |
| | *August* | 27(3.9%) | 44(6.4%) | 71(10.3%) |
| | *September* | 22(3.2%) | 40(5.8%) | 62(9%) |
| | *October* | 36(5.2%) | 31(4.5%) | 67(9.7%) |
| | *November* | 25(3.6%) | 37(5.4%) | 62(9%) |
| | *December* | 13(1.9%) | 32(4.6%) | 45(6.5%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

There is a statistically significant association between months of the year and degree of injury ($\chi^2(11)=24.488$, $p=0.011$; crv(11)=0.189). As expected, summer months (June and August) produced higher number of accidents involving backhoes, bulldozers, excavators and scrapers. One can say that due to the geographic and climatic diversity of the US, this is not surprising. Diverse climate allows construction industry to continue do work in different states throughout the year (Table 57).

According to Table 58, equipment types showed a statistically significant association with degree of injury for the on-foot workers (Table 56). Backhoes and excavators were responsible for most of the accidents as well as the fatalities. Backhoes have been identified as being responsible for 53.3% of the on-foot worker cases, followed by excavators (24.4%). Bulldozers (13.8%) and scrapers (8.6%) accounted for the remaining cases. In 32.2 % of the cases resulting fatality backhoes were involved. Moreover, 21.1% of the cases were nonfatal injury caused by backhoes.

Table 58: On-foot workers - Degree of injury vs Equipment Type

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Type | *Backhoe* | 145(21.1%) | 222(32.2%) | 367(53.3%) |
| | *Bulldozer* | 22(3.2%) | 73(10.6%) | 95(13.8%) |
| | *Excavator* | 76(11%) | 92(13.4%) | 168(24.4%) |
| | *Scraper* | 9(1.3%) | 50(7.3%) | 59(8.6%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Yet again, by dummy coding, the odds ratios for equipment types were calculated. It was found that even though scrapers and bulldozers are involved in considerably fewer accidents and fatalities resulting in accidents, they increase the odds of fatal injuries. An on-foot worker exposed to an accident involving scrapers is **3.49** times and bulldozers **2.097** times, more likely to die. In contrast, the odds ratio revealed that backhoes and excavators lowered the effect on the degree of injury relative to other equipment. The backhoes' odds ratio was found to be **0.76**, and this value for excavators is 0.62.

Findings from Table 58 supplement the equipment type findings in terms of the equipment involvement factor. Equipment attachment was the source of injury in 318 (46.1%) cases, with 269 (39%) of the cases accounting for body/superstructure involvement (Table 59). However, when equipment involvement in accidents is with their body/superstructure, this causes fatal injury more frequently than attachment or carried/lifted load.

Table 59: On-foot workers - Degree of injury vs Equipment Part Involvement

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Equipment Part Involvement | *Attachment* | 136 (19.7%) | 182(26.4%) | 318(46.1%) |
| | *Body/superstructure* | 67(9.7%) | 202(29.3%) | 269(39%) |
| | *Carried/lifted load* | 49(7.1%) | 53(7.7%) | 102(14.8%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

Backhoes and excavators have more moving parts compared to bulldozers and scrapers. Moreover, these equipment are less mobile compared to others on the jobs they perform. This finding highlights the importance of identifying the **danger zone** around heavy equipment. The danger zone can be defined as “the perimeter where equipment may have contact and result in injury or fatality to on-foot workers who work within this perimeter”. Danger zones differ among types of equipment as well as according to their movement. The danger zones of stationary equipment occur from rotating structures, the swing radius of attachments, and loads. For mobile equipment the danger zone includes blind spots and/or areas of limited visibility on the travel path. The dynamic structure of this zone makes it challenging to deal with from a countermeasure planning and implementation perspective.

All these three levels lead to struck-by or caught in/or between accidents. Recently, researchers tried to solve this problem with some advanced technological methods. Chi and Caldas (2011) proposed a method that automatically detects on-workers by using optical video cameras on the construction sites. In another effort, Tezier et. al. (2010) identified the blind spots for different equipment types and outlined such spots. According to their findings, excavators and scrapers have the largest areas constituting blind spots, followed by backhoe and bulldozer.  This finding also overlaps with the report that was published in 2004 by Center for Disease Control and Prevention. (CDC, 2003)

As shown in Table 60, the cross tabulation analysis revealed that struck-by (61.6%) is the highest frequency event type followed by caught in or between (23.1%) among on-foot workers.

Table 60: On-foot workers - Degree of injury vs Event Type

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatality | Total |
| Event Type | *Caught in or between* | 57(8.3%) | 102(14.8%) | 159(23.1%) |
| | *Electrocution* | 17(2.5%) | 35(5%) | 52(7.5%) |
| | *Fall from elevation* | 19(2.8%) | 15(2.1%) | 34(4.9%) |
| | *Other* | 14(2%) | 6(.9%) | 20(2.9%) |
| | *Struck-by* | 145(21%) | 279(40.6%) | 424(61.6%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

It is obvious that struck-by accidents cause a major concern for on-foot workers. OSHA also classifies struck-by accidents as one of the four major concerns (Focus Four) of the construction industry. When struck-by accidents are studied further in order to identify the types of struck-by accidents, as seen from the crosstabulation Table 61, on-foot workers were mostly struck by equipment (40.3%), which was closely followed by struck by attachment (30%), and the remainder of the cases were struck by falling attachment due to a mechanical problem (11.3%), falling object (12.7%) and swinging/flying object (5.7%).

Table 61: On-foot workers - Degree of injury vs Struck – by Event Details

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatality | Total |
| Event Type Details | Struck-by attachment | 48(11.3%) | 79(18.7%) | 127(30%) |
| | Struck-by equipment | 41(9.7%) | 130(30.6%) | 171(40.3%) |
| | Struck-by falling attachment | 23(5.4%) | 25(5.9%) | 48(11.3%) |
| | Struck-by falling object | 18(4.2%) | 36(8.5%) | 54(12.7%) |
| | Struck-by swinging/flying object | 15(3.5%) | 9(2.2%) | 24(5.7%) |
| Total | | 145(34.2%) | 279(65.8%) | 424 |

Environmental factors showed a statistically significant association with degree of injury. The Chi-square value was found to be significant ($\chi^2(9)=22.820$, $p=0.007$), but Cramer's V value (crv(9)=0.182) described this association as weak. When environmental factors were studied for on-foot workers (Table 62), material handling equipment/method accounted for 254 (36.9%) of the cases, which produced the highest frequency of fatal injury 180 (26.2%). It is followed by overhead moving/falling object action in 112 (16.3%) cases, and squeeze point action factor was present in 105 (15.2%) cases.

Table 62: On-foot workers - Degree of injury vs Environmental Factors

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Env. Factor | *Blind Spot* | 15(2.2%) | 28(4.1%) | 43(6.3%) |
| | *Catch point/puncture action* | 5(.7%) | 12(1.7%) | 17(2.4%) |
| | *Flammable liq./solid exposure* | 13(1.9%) | 4(.6%) | 17(2.5%) |
| | *Flying object action* | 11(1.6%) | 12(1.7%) | 23(3.3%) |
| | *Materials handling equip./method* | 74(10.7%) | 180(26.2%) | 254(36.9%) |
| | *Overhead moving/falling object action* | 46(6.7%) | 66(9.6%) | 112(16.3%) |
| | *Pinch point action* | 15(2.2%) | 21(3%) | 36(5.2%) |
| | *Squeeze point action* | 37(5.4%) | 68(9.9%) | 105(15.2%) |
| | *Work-surface/facility-layout condition* | 22(3.2%) | 27(3.9%) | 49(7.1%) |
| | *Other* | 14(2%) | 19(2.8%) | 33(4.8%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

When nonfatal injuries were investigated, yet again materials handling equipment/method accounted for 74 (10.7%) cases. This is followed by overhead moving/falling object action (46 cases).

There is a weak statistically significant association between the dependent variable and human factor (Table 56). According to Table 63, misjudgment of hazardous situation is the most frequently observed human factor in on-foot worker cases with 42.5%. This is followed by inappropriate choice/use of equipment and methods (21.8%). These two were also indentified as those leading to the highest fatal injury frequency. 192 (27.8%) of the fatalities were identified as cases where the victim's misjudgment played a role, followed by inappropriate choice/use of equipment /methods, with 102 (14.8%) cases. According to the odds ratio that was calculated by dummy coding, on-foot workers are **1.29** times more likely to be a victim of a fatal accident compared to when they make an inappropriate choice/use of equipment/methods. On the other hand, insufficient engineering and administrative controls increase the odds of fatal injury **1.85** times for the on-foot workers. This finding underlines the importance of engineering and administrative controls on a jobsite. When hazard controls are not sufficient enough to protect on-foot workers while working around earthmoving equipment, this brings the fatality risk closer to those workers in the event of an accident. Therefore, engineering and administrative controls should address all the hazards of earthmoving equipment, and proper PPE should be provided; moreover, adequate accident prevention methods should be followed for the well being of on-foot workers.

Table 63: On-foot workers - Degree of injury vs Human Factors

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Human Factor | *Distracting actions by others* | 3(.4%) | 3(.4%) | 6(.8%) |
| | *Human system malfunction* | 6(.9%) | 4(.6%) | 10(1.5%) |
| | *Inappropriate choice/use of eq./methods* | 48 (7%) | 102(14.8%) | 150(21.8%) |
| | *Inoperable/malfunctioned safety/warningdevices* | 46(6.7%) | 64(9.3%) | 110 (16%) |
| | *Insufficient eng. and admin controls* | 10(1.5%) | 31(4.5%) | 41(6%) |
| | *Misjudgment of hazardous situation* | 101(14.7%) | 192(27.8%) | 293(42.5%) |
| | *Other* | 38(5.5%) | 41(6%) | 79(11.5%) |
| Total | | 252(36.6%) | 437(63.4%) | 689 |

The age variable (Table 64) showed a statistically significant association with degree of injury for the on-foot workers cases ($\chi^2(10)=35.960$, p=0.000). This relationship found to be a weak relationship according to Cramer's V value (crv(10)=0.231).

Table 64: On-foot workers - Degree of injury vs Age

| | | Degree of injury | | |
|---|---|---|---|---|
| | | Nonfatal | Fatal | Total |
| Age | *<20* | 9(1.3%) | 21(3.2%) | 30(4.5%) |
| | *20-24* | 24(3.6%) | 48(7.1%) | 72(10.7%) |
| | *25-29* | 37(5.5%) | 53(7.9%) | 90(13.4%) |
| | *30-34* | 34(5%) | 53(7.9%) | 87(12.9%) |
| | *35-39* | 53(7.9%) | 61(9%) | 114(16.9%) |
| | *40-44* | 23(3.4%) | 60(8.9%) | 83(12.3%) |
| | *45-49* | 21(3.2%) | 46(6.8%) | 67(10%) |
| | *50-54* | 29(4.3%) | 27(4%) | 56(8.3%) |
| | *55-59.* | 10(1.5%) | 27(4%) | 37(5.5%) |
| | *60-64* | 1(.1%) | 18(2.7%) | 19(2.8%) |
| | *>64* | 0(0%) | 18(2.7%) | 18(2.7%) |
| Total | | 241(35.8%) | 432(64.2%) | 673 |

The “35-39” age group came out as having the highest occurrence percentage compared to other levels, with the 114 cases in this context count accounting for 16.9% of the cases. It also appeared to be the highest fatal injury observed age group, with 61 cases representing 9% of the total case numbers. It was very closely followed by the “40-44” age group, with 60 cases representing 8.9% of all the on-foot worker cases. The same age group also shows the highest nonfatal injury frequency, 53 cases.

### 4.3 The Binary Logistic Regression Analysis Findings

Three different models were created by using binary logistic regression analysis. Therefore, three different subsets were extracted from the main dataset. The extraction of cases was done as described in the following sections.

#### 4.3.1 Operator Model

As previously discussed and presented, crosstabulation gave us an understanding of how one single variable increases or decreases the odds of fatal injury in the event of an accident. However, it is probable that two or more variables may come into play at the same time; so, in order to investigate the combined effect of such variables, we carried out a binary logistic regression analysis.

We started modeling with the operators. The intent was to provide a model that could be used to predict the degree of injury for operators who ride one of the selected types of equipment (backhoes, excavators, bulldozers and scrapers) on construction sites. Hence, we ran a binary logistic regression analysis for a subset consisting of only "operator cases". This subset was extracted from the main dataset by filtering the "occupation" variable. A total of 376 operator cases were identified. Again, as discussed in the methodology section, this subset was divided into two sections; 70% (271 cases) was used to develop a model, and the remaining 30% (105) was used to validate the model.

Variable selection was conducted according to crosstabulation and univariate analysis results. For modeling, we included all the variables that showed significant association in crosstabulation analysis. The variables, their levels, and their coding and type that were entered in the binary logistic regression analysis to develop the "Operator Model" is presented in Table 65.

Table 65: Variables entered into analysis for Operator Model

| Variables used for analysis | Levels and Coding | Variable Type |
|---|---|---|
| 1. *Degree of injury (Dependent variable)* | Fatal:1<br>Non-fatal: 0 | Dichotomous |
| 2. *Union status* | Union:1<br>Nonunion: 0 | Dichotomous |
| 3. *Seat Belt Presence* | Present:1<br>Not present: 0 | Dichotomous |
| 4. *Cited for Safety Training* | Provided:1<br>Not provided: 0 | Dichotomous |
| 5. *Equipment Safety System* | Present :1<br>Not present: 0 | Dichotomous |
| 6. *Equipment Maintenance* | Present: 1<br>Not present: 0 | Dichotomous |
| 7. *SIC* | Provided:1<br>Not provided: 0 | Nominal |
| 8. *Equipment Type* | Backhoe: 1<br>Bulldozer: 2<br>Excavator: 3<br>Scraper: 4 | Nominal |
| 9. *Environmental Factor* | Materials handling equipment/method: 1<br>Work-surface/facility layout condition: 2<br>Overhead moving/falling object action: 3<br>Squeeze point action: 4<br>Pinch point action: 5<br>Flying object action: 6<br>Flammable liquid/solid exposure: 7<br>Catch point / puncture action: 8<br>Blind spot: 9<br>Other: 10 | Nominal |
| 10. *Human Factor* | Misjudgment of hazardous situation/; 1<br>Inappropriate choice/use of equipment/methods: 2<br>Inoperable/malfunctioned safety/warning devices: 3<br>Insufficient engineering and admin controls: 4<br>Human system malfunction: 5<br>Distracting actions by others: 6<br>Other: 7 | Nominal |

The base model had a naive predictive power of 69.9%, which indicates the overall percentage of correctly classified cases when there are no predictive variables in the model. Therefore, a model with added predictive variables has to improve the accuracy of this prediction. Loglikelihood value of the base model was found to be **267.629**. This value was used for the best model selection.

We started with the “stepwise backward enter” method. The 10 variables mentioned in Table 65 were entered into the analysis and by extracting insignificant ones, model iteration stopped at the fourth step. The analysis was performed at p=0.05 significance level to create the model. Table 66 and Table 67 summarize the results of this analysis.

When we closely examined the process, the model at the fourth step was the best of all for predicting the degree of injury. Its prediction power or accuracy was measured as 76.2%, which was greater than the naive predictor power. (see Table 66)

As one can see in the Table 67 footnote, the developed model’s loglikelihood value (233.969) is smaller than the loglikehood of the base model. We can thus conclude that the developed model is better at predicting the degree of injury than the base model where no predictor variables were added. When we take up the question of goodness of fit for the model, the Hosmer and Lemeshow test revealed that data fits the model satisfactorily. A poor fit is indicated by a significance value of less than .05; hence, the significance value of 0.757 is greater than 0.05 supports the goodness of fit for the model.

Table 66: Operator model classification table

| | | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Model Development Set** | | | **Validation Set** | | |
| | | Degree of injury | | % | Degree of injury | | % |
| **Observed** | | Nonfatal | Fatal | Correct | Nonfatal | Fatal | Correct |
| DV | Nonfatal | 17 | 41 | 29.3 | 11 | 17 | 39.3 |
| | Fatal | 17 | 169 | 90.9 | 11 | 93 | 89.4 |
| Overall % | | | | 76.2 | | | 78.8 |

As previously mentioned the data was split in two to develop and validate the model. Table 66 shows the prediction power of the model as 76.2%. It was also found that the same model correctly predicted **78.8%** of the validation data, which means the model more accurately predicts the degree of injury than the naïve prediction. Table 67 lists the variables in the model used to predict the degree of injury for selected heavy construction equipment operators in the event of an accident.

Table 67: Operator Model results

| **Variable** | B | S.E. | Wald | df | Sig. | Exp(B) | 95% C.I.for EXP(B) Lower | 95% C.I.for EXP(B) Upper |
|---|---|---|---|---|---|---|---|---|
| Safety Program(1) | .967 | .433 | 4.989 | 1 | .026 | 2.631 | 1.126 | 6.149 |
| Safety Training(1) | -1.352 | .376 | 12.900 | 1 | .000 | .259 | .124 | .541 |
| Union Status(1) | -1.024 | .375 | 7.436 | 1 | .006 | .359 | .172 | .750 |
| Equipment Protective Systems | -1.187 | .512 | 5.370 | 1 | .020 | .305 | .112 | .833 |
| Constant | 2.442 | .564 | 18.743 | 1 | .000 | 11.496 | | |

* -2 Loglikelihood = 233.969; Hosmer and Lemeshow Chi-square Test $\chi^2(7)=4.192$, p=0.757

In light of this information safety program (SP), safety training (ST), union status (US) and equipment protective systems presence (EPS) have a significant effect on degree of injury. By examining the β coefficients, it was revealed that all variables except for “safety program” have a decreasing effect on the probability of a fatal injury.

Table 68: Relative importance of variables in the operator model

| | Model Log Likelihood | Change in -2 Log Likelihood | df | Sig. of the Change |
|---|---|---|---|---|
| Safety Program | -119.440 | 4.911 | 1 | .027 |
| Safety Training | -124.280 | 14.591 | 1 | .000 |
| Equipment Protective Systems | -120.264 | 6.558 | 1 | .010 |
| Union Status | -120.638 | 7.308 | 1 | .007 |

When we questioned which variable is important for the model, we used the loglikelihood value change as a measure factor. As one can see in Table 68, removing the safety training variable changes the loglikelihood of the model more than the other variables in the model.

### 4.3.2 On-foot Worker Model

The on-foot worker model was developed with the intent of predicting the degree of injury for on-foot workers who work around one of the selected equipment (backhoes, excavators, bulldozers and scrapers) on construction sites. Consequently, we ran a binary logistic regression analysis again for a subset consisting of only "on-foot worker" cases. Yet again, this subset was extracted from the main dataset by filtering the "occupation" variable. A total of 689 cases were identified and divided into two sections; 70% (480 cases) was used to develop a model, and the remaining 30% (209 cases) was used to validate the model.

The variable selection was carried out according to crosstabulation and univariate analysis results. Variables listed in Table 69 were entered in a binary logistic regression analysis to develop the "On-Foot Worker Model". It should be noted that variables that showed significant association in crosstabulation analysis were chosen for this modeling attempt. Only the age variable was used as a continuous variable. Other variables were entered as categorical variables.

Binary logistic regression analysis was performed by the stepwise method to develop the best model. The base model showed a naive predictive power of 65.3%, and this base model's loglikelihood value was found to be **606.722**.

The stepwise backward enter method was conducted by entering ten variables. Insignificant variables were extracted until no insignificant variables remained. The analysis was performed at the p=0.05 significance level to create the model. Model iteration was stopped in the third step.

Table 69: Variables entered into analysis for On-Foot Worker Model

| Variables used for analysis | Levels and Coding | VariableType |
|---|---|---|
| 1. *Degree of injury (Dependent variable)* | Fatal:1<br>Non-fatal: 0 | Dichotomous |
| 2. *Union status* | Union:1<br>Nonunion: 0 | Dichotomous |
| 3. *Back-up Motion Presence* | Present :1<br>Not present: 0 | Dichotomous |
| 4. *Back-up Alarm Prs./Cond.* | Working: 1<br>Not Working: 0 | Dichotomous |
| 5. *Safety Training* | Provided:1<br>Not provided: 0 | Dichotomous |
| 6. *Equipment Protective System* | Present :1<br>Not present: 0 | Dichotomous |
| 7. *Equipment Type* | Backhoe: 1<br>Bulldozer: 2<br>Excavator: 3<br>Scraper: 4 | Nominal |
| 8. *Environmental Factor* | Materials handling equipment/method: 1<br>Work-surface/facility layout condition: 2<br>Overhead moving/falling object action: 3<br>Squeeze point action: 4<br>Pinch point action: 5<br>Flying object action: 6<br>Flammable liquid/solid exposure: 7<br>Catch point / puncture action: 8<br>Blind spot: 9<br>Other: 10 | Nominal |
| 9. *Human Factor* | Misjudgment of hazardous situation/; 1<br>Inappropriate choice/use of equipment/methods: 2<br>Inoperable/malfunctioned safety/warning devices: 3<br>Insufficient engineering and admin controls: 4<br>Human system malfunction: 5<br>Distracting actions by others: 6<br>Other: 7 | Nominal |
| 10. *Age* | 16-75 | Continuous |

Upon close examination, the third model was the best to predict the degree of injury. Its prediction power was calculated as 76.2%, which was greater than the naive predictor power.

Table 70 and Table 71 illustrate the developed model's results. As one can see, loglikelihood value for the model is smaller than the loglikelihood of the base model (-2 Log likelihood = 531.432). We can conclude that the developed model is better at predicting the degree of injury.

As a next step, we examined the goodness of fit of the model to the data, Hosmer and Lemeshow revealed that data fits the model satisfactorily. Poor fit is indicated by a significance value less than .05, and the developed model's significance value was calculated as 0.443, greater than 0.05. This finding supports the goodness of fit for the model.

Table 70: On-foot worker model classification table

| | | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | Model Development Set | | | Validation Set | | |
| | | Degree of injury | | % | Degree of injury | | % |
| **Observed** | | Nonfatal | Fatal | Correct | Nonfatal | Fatal | Correct |
| DV | Nonfatal | 68 | 95 | 41.7 | 28 | 50 | 35.9 |
| | Fatal | 43 | 264 | 86.0 | 24 | 101 | 80.8 |
| Overall % | | | | 70.6 | | | 73.5 |

Table 71 presents the results of how the selected model correctly classifies the cases in the groups of degree of injury. It also tests the model in the validation set and presents its results in the same table. The prediction power of the model is 70.6%. It was also found that the same model correctly predicted 73.5% of the validation data set which means this model more accurately predicts the degree of injury than the naive model.

Variables in the model to predict the degree of injury for selected earthmoving equipment operators in the event of an accident is illustrated in Table 71.

Table 71: On-foot worker model results

| Variable | B | S.E. | Wald | df | Sig. | Exp(B) | 95% C.I.for EXP(B) Lower | Upper |
|---|---|---|---|---|---|---|---|---|
| Equipment Type | | | 13.183 | 3 | .004 | | | |
| Bulldozer(1) | .631 | .326 | 3.754 | 1 | .053 | 1.880 | .993 | 3.562 |
| Excavator (1) | -.397 | .256 | 2.397 | 1 | .122 | .672 | .407 | 1.111 |
| Scraper(1) | 1.165 | .513 | 5.162 | 1 | .023 | 3.207 | 1.174 | 8.765 |
| Union Status(1) | -.887 | .239 | 13.758 | 1 | .000 | .412 | .258 | .658 |
| Safety Training(1) | -1.254 | .218 | 33.123 | 1 | .000 | .285 | .186 | .438 |
| Age | .026 | .009 | 8.132 | 1 | .004 | 1.026 | 1.008 | 1.044 |
| Constant | .555 | .368 | 2.270 | 1 | .132 | 1.742 | | |

* -2 Loglikelihood = 531.432; Hosmer and Lemeshow Chi-square Test $\chi^2(7)$= 7.903, p=0.443

According to this given information, equipment type, safety training, union status and age had a significant effect on the degree of injury. By examining the β coefficients, it was revealed that age and equipment type had an increasing effect whereas union status and safety training showed a decreasing effect on the probability of the fatal injury.

Table 72: Relative importance of variables in the on-foot worker model

| | Model Log Likelihood | Change in -2 Log Likelihood | df | Sig. of the Change |
|---|---|---|---|---|
| Equipment Type | -273.068 | 14.703 | 3 | .002 |
| Union Status | -272.650 | 13.868 | 1 | .000 |
| Safety Training | -283.424 | 35.415 | 1 | .000 |
| Age | -269.975 | 8.518 | 1 | .004 |

Table 72 displays the information how the model is affected if that if a predictor variable is removed from the model. Therefore, we can use this information to gauge the importance of a variable in the model. As one can see, the removal of safety training from the model makes the biggest change in the model’s log likelihood value. Therefore, safety training is the most important variable in this model. It is followed by equipment type, union status and age, respectively.

### 4.3.3 Backhoe Model

The backhoe model was developed with the intent of showing that a model can be used to predict the degree of injury for workers who ride them or work around them on construction sites. Hence, a binary logistic regression analysis was conducted for a subset of data compiled on only “backhoe” cases. This subset was extracted from the main dataset by filtering the “equipment type” variable. A total of 507 cases were identified. Once more, this subset was divided into two sections: 70% (354 cases) to develop a model and the remaining 30% (153 cases) to validate the model.

The variables in Table 73 were selected for the backhoe model after performing a univariate analysis side study. Human factors, environmental factors, and activity prompting accident variables were converted to dichotomous variables, which means they became “dummy variables”. Dummy variables are defined as “the variables resulting from recoding categorical variables with more than two levels into a series of binary (dichotomous) variables”. In this case, we assigned 1 to the category with the highest frequency count and 0 to all others. For example, for human factor variable, misjudgment of the hazardous situation level had 47 % of the frequency counts; therefore, we assigned the value 1 and coded all others as 0.

For a third time, a binary logistic regression analysis was performed by using the stepwise method. It was found that the base model had a naive predictive power of 63.3% and a loglikelihood value of **465.486**.

Table 73: Variables entered analysis for backhoe model

| Variables used for analysis | Levels and Coding | Variable Type |
|---|---|---|
| 1. *Degree of injury (Dependent variable)* | Fatal:1<br>Non-fatal: 0 | Dichotomous |
| 2. *Union status* | Union:1<br>Nonunion: 0 | Dichotomous |
| 3. *Back-up Motion Presence* | Present :1<br>Not present: 0 | Dichotomous |
| 4. *Back-up Alarm Presence/Condition* | Working: 1<br>Not Working: 0 | Dichotomous |
| 5. *Rollover Protection Str.* | Present :1<br>Not present: 0 | Dichotomous |
| 6. *Cited for Safety Training* | Provided:1<br>Not provided: 0 | Dichotomous |
| 7. *Equipment Safety System* | Present :1<br>Not present: 0 | Dichotomous |
| 8. *Equipment Maintenance Problem* | Present : 1<br>Not present: 0 | Dichotomous |
| 9. *Environmental Factor* | Materials handling equipment/method: 1<br>Other: 0 | Dichotomous |
| 10. *Human Factor* | Misjudgment of hazardous situation; 1<br>Other: 0 | Dichotomous |

First, 10 variables were entered into the analysis, and a “stepwise backward enter” was used for model iteration. By extracting the insignificant ones, the model iteration stopped in the fourth step. The confidence interval again was chosen as 95%. The best model was created at the last step to predict the degree of injury. Its prediction power was measured as 66.4%, which was greater than its naive predictor power. (see Table 74) We concluded that the developed model and chosen model was better at predicting whether degree of injury than base model in terms of loglikelihood value. As one can see in Table 75, loglikelihood value for the model is smaller than the the loglikelihood of the base model.

The developed model’s Hosmer and Lemeshow test results revealed that the data fits the model satisfactorily according to the goodness of fit criterion. Significance value p=0.663 supports the goodness of fit for the model compared to 0.05.

Table 74: Backhoe model classification table

| | | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Model Development Set** | | | **Validation Set** | | |
| | | Degree of injury | | % | Degree of injury | | % |
| **Observed** | | Nonfatal | Fatal | Correct | Nonfatal | Fatal | Correct |
| DV | Nonfatal | 34 | 96 | 26.2 | 5 | 41 | 10.9 |
| | Fatal | 23 | 201 | 89.7 | 8 | 99 | 92.5 |
| Overall % | | | | 66.4 | | | 68.0 |

As previously mentioned, Table 74 displays the model's classification results. Model classification shows the prediction power of the model as 66.4%; this value is slightly higher than the naïve prediction power of the base model. Moreover, when the selected model was applied on the validation set, it correctly predicted 68%.

Table 75 presents the variables in the backhoe equipment model to predict the degree of injury.

Table 75: Backhoe model results

| **Variables** | | | | | | | 95% C.I.for EXP(B) | |
|---|---|---|---|---|---|---|---|---|
| | B | S.E. | Wald | df | Sig. | Exp(B) | Lower | Upper |
| Safety Training(1) | -1.203 | .245 | 24.082 | 1 | .000 | .300 | .186 | .486 |
| Union Status(1) | -.798 | .261 | 9.361 | 1 | .002 | .450 | .270 | .751 |
| Constant | 1.489 | .211 | 49.866 | 1 | .000 | 4.431 | | |

* -2 Loglikelihood = 427.723; Hosmer and Lemeshow Chi-square Test $\chi^2(2)= 0.821$, p=0.663

According to analysis results, the model consists of only two predictor variables. Safety training and union status were the only variables among the others showing a significant effect on the degree of injury. By examining the β coefficients, it was revealed that both variables have a decreasing effect on the probability of the fatal injury.

Table 76: Relative importance of variables in the backhoe model

| | Model Log Likelihood | Change in -2 Log Likelihood | df | Sig. of the Change |
|---|---|---|---|---|
| Safety Training | -226.798 | 25.873 | 1 | .000 |
| Union Status | -218.555 | 9.386 | 1 | .002 |

According to the information in Table 76, the removal of safety training makes a greater change in the model's loglikelihood value compared to union status. Hence, we concluded that safety training is a more important variable than union status in regards to affecting the model's prediction power.

If we summarize our findings through binary logistic regression analysis, we successfully developed three different models: operator, on-foot worker and backhoe models. By comparing the results of logistic regression analysis, the following can be concluded:

1. Safety training and union status have a decreasing effect on each of the three models.
2. Additional to safety training and union status, safety manual and equipment protective systems are the other predictor variables in the "operator model". The safety manual showed an increasing effect on fatalities whereas equipment protective system presence had a decreasing effect on fatality.
3. Age and equipment type are other predictor variables in the "on-foot worker model". Age has a slightly increasing effect on fatal injuries. While backhoes, bulldozers and scrapers increase the odds of a fatal injury, excavators have a decreasing effect on the degree of injury. However, excavator's effect is not statistically significant.

4. The backhoe model only consists of union status and safety training, which will decrease the odds of fatal injury as mentioned earlier.

# CHAPTER 5

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study presented in this dissertation was undertaken to identify and analyze the factors associated with the fatalities and nonfatal injuries resulting from construction accidents involving earthmoving equipment. Univariate statistical analyses were performed to establish frequency distributions of the factors, and multivariate crosstabulation analyses were conducted to establish associations between the degree of injury (fatal vs nonfatal outcomes) and mentioned factors to determine significance. Subsequently, logistic regression widely was carried out to predict future outcomes in terms of significant influencing factors. The conclusions drawn from this research are summarized below.

Lack of safety awareness of hazards and failure to follow adequate accident prevention methods or safe work practices constitute most of the earthmoving equipment related accidents. This insufficient knowledge of safe work practices commonly results in misjudgment of hazardous situations and inappropriate choice/use of equipment/methods as human errors. When these identified human errors on the jobsites are combined with an unsafe environment, both constitute an increased risk of fatal injury involving operator or on-foot workers, and sometimes both.

The findings of this study also revealed that the two hazards, struck-by and caught in/or between, are involved in 80 percent of all earthmoving equipment accidents and correspond with the “focus four” causes of accidents per OSHA in construction sites.

Factors describing and classifying earthmoving equipment related accidents in relationship with the degree of injury involving on-foot workers and operators were found to be slightly different. After conducting crosstabulation analysis it was concluded that for earthmoving operators, fatal injury outcome is in statistically significant association with seat belt presence on equipment, union status, adequate safety training, equipment protective system, equipment maintenance, SIC, equipment type event type, environmental factor, human factor, and age factor. The operators using well maintained earthmoving equipment with all protective systems in place is crucially important. Operators riding equipment with malfunctioned or no protective system are **2.90** times more likely be a victim of a fatality in the event of an accident. Furthermore, fastening the seat belt at all times during the job they perform not only decreases the odds of fatal injury but also prevents a citation in the event of an OSHA inspection. In order for operators to follow these rules, increasing their safety awareness is the key. Safety training is the tool for this purpose. Besides safety training, supervision of safe work practices, carried out systematically on the job site, is another decreasing factor for fatal injuries. Job sites where union workers are present should be exemplary for the construction industry; how they train their members, how they enforce safety rules, and how they supervise safety at the job site, what they require from a job owner, etc. should be studied and adopted by others.

On the other hand, for on-foot workers the degree of injury showed statistically significant association with the reverse motion of equipment, back-up alarm condition, union status, safety program, safety training, equipment protective system, months of the year, equipment type, environmental factor, human factor and age factors. Working around earthmoving equipment with all the protective systems, and equipped with loud enough back-up audible alarms which alert them when equipment in reverse motion decreases the odds of a fatal injury outcome for the on-foot workers. Not only these but also working at a jobsite where adequate safety (accident prevention) program is in place and enforced also is concluded to be reduce the odds of a fatal injury. Furthermore, being adequately trained for the hazards associated with the work they perform and the job site also helps on-foot workers protect themselves from being a victim of a fatal injury. Yet again, lessons should be learned from unions regarding how they minimize unsafe working conditions.

Based on logistic regression analysis results, it was concluded that different predictive models can be developed to distinguish between accidents involving different workers and equipment categories influencing the degree of injury.

The developed operator model included the variables safety program, safety training, union status and equipment protective systems. Safety training, union status and equipment protective system decrease the fatal injury odds, whereas a safety program was found to increase these odds.

The on-foot worker model included equipment type, union status, safety training and age. Union status and safety training lower the degree of injury.  Age has a slightly increasing effect on fatal injury. While backhoes, bulldozers and scrapers increase the odds of fatal injury, excavators have a decreasing effect on the degree of injury. However, excavators' effect is not statistically significant.

The backhoe model only consists of union status and safety training, which will decrease the odds of fatal injury as mentioned earlier.

From the results of the multivariate analysis, it is proven to have the possibility of predicting a future outcome. Therefore, one can take necessary remedial steps to decrease the risk of degree of injury.

Based on the analyses performed in this study and findings, the following recommendations can be advanced:

For future research we recommend that carrying out odds ratio and logistic regression modeling on each of the FOCUS FOUR hazards for specific trades in the construction industry. Similar studies can be performed by selecting a different dependent variable such as accident type.

The OSHA IMIS database is maintained very well and a great source for safety researchers; however, inconsistency in some cases makes it difficult for researchers to come up with conclusions.  OSHA's coding system needs to be improved based on the researcher's suggestions here. Hence, consistent and detailed information would then be used by researchers precisely so that better conclusions can be driven.

# APPENDIX – A: SAMPLE OSHA ACCIDENT INVESTIGATION REPORT



Return to Result Page

**Accident: 200624229 - Employee Is Killed When Backhoe Tips Over**

**Accident: 200624229 -- Report ID: 0454712 -- Event Date: 03/13/2007**

| Inspection | Open Date | SIC | Establishment Name |
|---|---|---|---|
| 310709001 | 03/14/2007 | 1711 | Quality Contractors Inc |

On March 13, 2007, Employee #1 was working for a contractor that engaged in plumbing, heating, air-conditioning, and similar work. He was preparing to dig a ditch for a fill line at a residential construction site. A large limb from a tree had fallen into the path where the fill line was to be placed, and Employee #1 was using the front bucket of his backhoe to move the limb out of the way. The area where Employee #1 was operating the backhoe was sloped. A neighbor who was driving down the driveway saw the backhoe on its side with the alarm going off and called the police. It appeared that Employee #1 was thrown from or fell from the backhoe when it tipped over and that Employee #1 was not wearing a seatbelt at the time. Employee #1's abdomen was crushed by the cab of the backhoe, and he was killed.

**Keywords:** construction, backhoe, slope, overturn, seat belt, ejected, work rules, crushed, abdomen

| End Use | Proj Type | Proj Cost | Stories | NonBldgHt | Fatality |
|---|---|---|---|---|---|
| Single family or duplex dwelling | New project or new addition | $250,000 to $500,000 | 1 | | X |

| | Inspection | Age | Sex | Degree | Nature | Occupation | Construction |
|---|---|---|---|---|---|---|---|
| 1 | 310709001 | | | Fatality | Other | Occupation not reported | **FallDist:** <br> **FallHt:** <br> **Cause:** Site clearing and grubbing <br> **FatCause:** Crushed/run-over/trapped of operator by operating |

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Return

| | |
|---|---|
| **Inspection Nr** | 310709001 |
| **Investigation Nr** | 200624229 |
| **Line Nr** | 1 |
| **Age** | |
| **Sex** | |
| **Nature of Injury** | Other |
| **Part of Body** | Abdomen |
| **Source of Injury** | Materials Handlg Eq. |
| **Event Type** | Caught In Or Between |
| **Environmental Factor** | Materials Handlg Equip./Method |
| **Human Factor** | Misjudgment, Haz. Situation |
| **Occupation** | Occupation not reported |
| **Degree of Injury** | Fatality |
| **Task Assigned** | Task regularly assigned |

**Inspection: 310709001 - Quality Contractors Inc**

**Inspection Information - Office: Tenn Cmpl Sfty 2**

Nr: 310709001 Report ID:0454712 Open Date: 03/14/2007

Quality Contractors Inc
1252 Old Hwy 99
Columbia, TN 38401 Union Status: NonUnion
SIC: 1711/Plumbing, Heating and Air-Conditioning
NAICS: 238220/ Plumbing, Heating, and Air-Conditioning Contractors
Mailing: 1201 South High St, Columbia, TN 38401

Inspection Type: Accident
Scope: Partial Advanced Notice: N
Ownership: Private
Safety/Health: Safety Close Conference: 03/15/2007
Planning Guide: Safety-Construction Close Case: 07/31/2007

| Optional Information: Type | ID | Value |
|---|---|---|
| N | 10 | IMMLANG-N |

| Related Activity: Type | ID | Safety | Health |
|---|---|---|---|
| Accident | 100624337 | | |

**Violation Summary**

| | Serious | Willful | Repeat | Other | Unclass | Total |
|---|---|---|---|---|---|---|
| Initial Violations | 1 | | | 1 | | 2 |
| Current Violations | 1 | | | 1 | | 2 |
| Initial Penalty | 1600 | | | 400 | | 2000 |
| Current Penalty | 1600 | | | 400 | | 2000 |
| FTA Amount | | | | | | |

**Violation Items**

| # | ID | Type | Standard | Issuance | Abate | Curr$ | Init$ | Fta$ | Contest | LastEvent |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 01001 | Serious | 19260028 A | 04/23/2007 | 05/06/2007 | $1600 | $1600 | $0 | | - |
| 2. | 02001 | Other | 3000327 A | 04/23/2007 | 05/23/2007 | $400 | $400 | $0 | | - |

## APPENDIX – B: OSHA DATA VALIDATION

Integral to performance measurement is understanding data limitations, correcting these limitations when cost-effective, and learning to manage for results when data are known to be imperfect. OSHA will rely on performance data generated by the Agency as well as data from outside sources. OMB Circular A-11 addresses the verification and validation of performance measurement data from outside sources and states that an agency is not required to develop an independent capacity for validating or verifying performance data received from or based on sources outside the Agency.

However, in collecting data for OSHA programs, the assessment and, where possible, the elimination of sources of error has always been an important task for OSHA data program managers. Validation of performance measures and indicators will be addressed through a variety of means:

- Quality assurance is an integral part of the OSHA data initiative collection process. The Agency has initiated a comprehensive approach to monitoring and improving the accuracy of the OSHA-collected data. The data included in the data base must pass various data edits and employers are contacted to correct any deficient data. In FY 1997, OSHA conducted a data collection validation study of Calendar Year 1995 data collected during Calendar Year 1996.
- OSHA is conducting annual on-site audits of the injury and illness records of a random selection of employers participating in the Data Initiative to determine the accuracy and reliability of the OSHA 200 Logs, the source of data for the OSHA Data Initiative and BLS Annual Survey. The Recordkeeping audit program is an ongoing annual audit program that validates the consistent quality of the data. These establishment-based audits compare the injuries, illnesses, and fatalities recorded on the OSHA 200 Log with the employer's workers' compensation records, exposure and medical records, and other records.

- Additional quality assurance for source injury and illness data is provided by OSHA. This quality assurance effort includes an information and outreach program, and enforcement of the injury and illness recordkeeping regulations. OSHA is also revising its injury and illness recordkeeping system (regulations, forms and guidelines) to improve the quality of records by simplifying forms and regulations, providing clearer guidance for employers, and incorporating incentives for employers to maintain high quality records.
- OSHA's Integrated Management Data System (IMIS) uses various methods for validating and verifying data used in performance measurement:
    - Comparison with previous data from the IMIS
    - Comparison with another reliable source of the same type of data within OSHA (IMIS and OCIS)
    - Edits contained within IMIS
- All field offices were required to review all significant and egregious cases for the last three years and correct them as appropriate
- There is a disclaimer to the OSHA Internet site telling an employer or worker what to do if they believe the data are incorrect. It directs the user to the Area or State Office responsible for the inspection for resolution of the issues.
- OSHA is preparing to place in the Agency's IT operating plan for next fiscal year a proposal to select a random national sample of settlement agreements annually for Area Offices to review and verify that the information contained in the IMIS is accurate.
- OSHA is also modifying the language in citation transmittal letters to inform companies that IMIS inspection data are available on the Internet and that they should contact the Agency immediately for correction, if they find their data to be inaccurate.

OSHA believes that the system for ensuring correct data in the IMIS system is working. There have been no complaints about IMIS data records since March 1998 when public access to enforcement data on the Internet was restored.

In revising this Strategic Plan, OSHA has reviewed U.S. General Accounting Office observations on the Department's FY 1999 Performance Plan (GAO/HEHS-98-175R) and related testimony (GAO/T-HEHS-98-88) concerning OSHA's Integrated Management Information System, and does not find that the issues raised effect the validity of the Agency's IMIS-based GPRA performance measures. The Agency will work with the Department of Labor's Office of the Inspector General to evaluate the validity of its performance measures.

For some of OSHA's performance indicators, there is a time lag between the activity, the data collection, and the reporting of data. The availability of BLS injury and illness data involves a time lag of about a year, while the OSHA Data Initiative data involves a time lag of 10–11 months. Likewise, BLS fatality data involves a time lag of about 8 months. This creates difficulty for OSHA's monitoring and reporting on performance on an annual basis. Data timeliness is further complicated because GPRA requires tracking on a fiscal year basis, while OSHA's Data Initiative and the BLS produce data on a calendar year basis. Also, CFOI reports on the date of death, not the date of injury. However, the OMB Circular No. A-11 (Revised), July 1, 1998, clearly recognizes the data timeliness concern and addresses the issue of a time lag. Section 220.10(g) states "GPRA makes allowance for this situation by requiring that the annual program performance report include results only when data becomes available." IMIS data are updated daily, and final end-of-year IMIS data is available six weeks after the end of a fiscal year.

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# ABSTRACT

## ANALYSIS OF FATAL AND NON-FATAL ACCIDENTS INVOLVING EARTHMOVING EQUIPMENT OPERATORS AND ON-FOOT WORKERS

by

**Emrah Kazan**

August 2013

**Advisor:** Mumtaz Usmen, PhD, PE

**Major:** Civil Engineering

**Degree:** Doctor of Philosophy

In view of the limitations of univariate statistics for studying construction accidents, a multivariate approach was undertaken using crosstabulation analysis and logistic regression.

Heavy construction equipment accidents related data for four type of equipment; backhoes, bulldozers, excavators and scrapers were incorporated in the study using categorical variables. Degree of injury indicating the severity of accident outcome (fatal vs. nonfatal) was selected as the dependent variable, and a variety of factors potentially affecting the outcome comprised the independent variables. Cross tabulation results enabled the understanding and evaluation of associations between the research variables, while logistic regression yielded predictive models that helped describe accident severity in terms of the contributing factors. Factors increasing or decreasing the odds of accident severity (degree of injury) in the presence or absence of various factors were identified and quantified. It was concluded that multivariate analysis serves as a much more powerful tool than univariate methods in eliciting information from construction accident data. Union status of workers and the safety training they were

provided according to OSHA guidelines vastly affect the degree of injury and lessen the odds of fatality.

# AUTOBIOGRAPHICAL STATEMENT

Esref Emrah Kazan graduated from Suleyman Demirel University, Turkey in 2000 with a B.S. degree in civil engineering. He came to the U.S. in 2001, and attended Wayne State University in Detroit, Michigan to pursue his master's degree in Civil Engineering in 2002. He earned a Master of Science in Civil Engineering degree in 2004. Three years later, he pursued his studies in construction management PhD degree program at Wayne State University.

Emrah Kazan is currently working as a Project Engineer in a private company. He is involved in all aspects of construction project management from pre-construction and construction through closeout phases including providing procurement and construction oversight as well as administering budgets, schedules, cost issues and change order processes in Waste Water Treatment Plant projects. He is also working as a part time faculty at the Wayne State University Civil and Environmental Engineering Department. He teaches graduate and undergraduate level courses. Some of the courses he teaches are Introduction to CAD in Civil Engineering, and BIM - Building Information Modeling and Construction Safety.

Previously, he served as a Graduate Research Assistant, Graduate Teaching Assistant and Research Fellow for Wayne State University during his graduate education.