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AN ANALYTICAL STUDY OF CRITICAL FACTORS OF LIFT PLANNING TO IMPROVE CRANE SAFETY BASED ON FORENSIC CASE STUDIES OF CRANE ACCIDENTS

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by

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Dedication

This dissertation is dedicated to my loving wife, friend, and greatest supporter, Majane. Your never-ending support, as well as understanding of the long hours, was critical to completing this project. I would also like to dedicate this work to my father whose loving guidance, encouragement, and direction provided a solid foundation for a wonderful career in engineering. You were my mentor and idol as you guided me through the maze of construction life and respect for cranes.

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Abstract

An Analytical Study of Critical Factors of Lift Planning to Improve Crane Safety Based on Forensic Case Studies of Crane Accidents

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Cranes, both mobile and static, are mechanical devices that rely on leverage and balance between the loads and the counterweight to lift, move, and place those loads. Cranes are used in virtually every industry, around the world, and are critical and indispensable tools for the dynamic and continually changing nature of construction. Despite the utilization of cranes, in almost all industries, humans operate those cranes, meaning that human intervention is necessary to rig loads, signal crane maneuvers, operate the crane itself, and carry out safety measures that ensure tasks are properly completed. Proper lift planning requires the person directing the operation understand lift risks, know how to address potential hazards, and communicate that knowledge regarding risks, hazards, and safety requirements to members of the lift crew. Interactions among personnel who are involved in lifts requires planning, training, and collaboration. Each person must correctly perform his or her duties and execute assigned responsibilities as deemed necessary.

Over a period of 30 years, the researcher has analyzed more than 1000 crane accidents and accumulated specific data compiled from 701 of those accidents to analyze

accident details and develop evaluations of factors contributing to accidents. This study's researcher has utilized forensic accident analysis methods to assist in the development of crane related protocol suggestions, which, if implemented in the field, should decrease the likelihood of accident and consequent injuries, deaths, and property damages. Of the 701 accidents examined in this study, human interventions caused 651 (92.9%) of the incidents. Only 50 (7.1%) of the accidents were caused by machine or mechanical issues. These findings conclusively demonstrate the importance of determining why these accidents have occurred.

Based upon the research findings, the researcher has highlighted safety strategies that may be utilized to develop crane lift planning practices, which use hazard identifications and responsibility assignments in accordance with ASME B30.5-2007. The statistical findings indicate that the crane lift processes and resulting accidents are heavily influenced by human error and inadequate communication methods among members of the lifting crew. Communication was cited by CII as the greatest enabler, including feedback from workers that was found to enhance safety.

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Chapter 1: Introduction to Cranes

Cranes are indispensable tools used in construction and other industries which lift loads of varying weights, distances, heights, and environments. Changes of working variables (i.e., building size, height, weather conditions, job size load often result in accidents which damage buildings and cause injuries and fatalities to workers, other field personnel, and even innocent bystanders (Häkkinen 1993). Past studies (Hinze and Russell 2006; Hinze et al. 1998; Suruda et al. 1997) of crane accidents have been limited to fatality statistics collected and prepared by the Occupational Safety and Health Administration's (OSHA) Integrated Management and Information System (IMIS). IMIS does not address accident causation and does not contain reliable crane accident causation data (Shapria and Lyachin 1997).

Determination of causes for an incident is a first step in identifying and understanding risks taken which led to an accident. Procedures identified by analyses of these risks can reduce the likelihood of future accidents. Reactionary methods of addressing accidents, unfortunately, have limited effect in reducing the likelihood of future accidents (Häkkinen 1993). According to Häkkinen (1993), a large database providing analyses of causes for crane accidents and methods by which accidents can be prevented, based upon noted hazards, risks taken, and other accident triggers, can be effective in ensuring the implementation of deliberate measures to reduce accidents. Organizations strive for performance, both production and safety (Kannan et al. 2016). A large comprehensive database provides guidance for academic research. Incident databases are the core for building the data analysis tree (Kannan et al. 2016).

This study highlights safety strategies that may be utilized to develop crane lift planning practices which use hazards identification and responsibility assignments for each hazard. Furthermore, throughout Chapter 1, the researcher has identified common crane hazards and discusses duties and responsibilities of associated crane lift personnel. Information developed during forensic engineering analyses of crane accident causes and associated determinations of the duties and responsibilities of personnel, can be used to address common hazards and improve safety. Chapter 1 also highlights critical information which has guided the researcher during his development of the research vision and research questions.

1.1 Problem Statement

Cranes are evolving tools used in many industries which enable workers to lift ever heavier loads to greater heights. While there are benefits associated with greater lifting and reach ability, the complexity of projects and jobsite concerns must be taken into account when cranes are employed. Increasing crane performance and complexity potentially can expose jobsite workers to new hazards each of which must be identified and resolved prior to lift initiation. Jobsite workers are exposed to potentially new hazardous conditions with increased complexity, which must be identified and resolved prior to initiating a lift (Raviv, Shapira, and Fishbain 2017).

Neitzel et al. (2001) observed that crane accidents occur fairly often on construction projects. In fact, as many as one-third of all construction and maintenance injuries and fatalities involve cranes (Neitzel et al. 2001). Despite high rates of crane-related injuries and fatalities in the construction industry, Veazie et al. (1994) identified a scarcity of epidemiological studies of construction accidents and highlighted the fact that that even fewer studies have identified causes of crane-related accidents. This study provide research based on a large database which allows for more in-depth analysis and interactions of data.

Prior experience can be key to preparing for the future (Häkkinen 1993). Researchers and practitioners should examine in detail those causes of past accidents. Much can be learned from past mistakes. When accurate identifications of factors contributing to accidents are documented and understood, preventative procedures (i.e., certifications, risk recognition risk correction, and safety trainings) will be more effective (Hinze and Russell 2006). The Occupational Safety and Health Administration (OSHA) has collected considerable data regarding crane-related accidents and assimilated it into the Integrated Management Information System (IMIS). IMIS provides information regarding construction related fatality statistics but no information regarding accident causation. Despite a thorough review of databases and research publications, the researcher has confirmed that there is no database available which addresses causation. Causation information would be extremely valuable in identifying hazards associated with crane accidents.

The researcher of this study has utilized forensic accident analysis method to assist in the development of crane related protocol suggestions which if implemented in the field should decrease the likelihood of accident and consequent injuries, deaths, and property damage. This study addresses the database information gap using data derived from forensic analyses of causes for crane-related accidents, incorporating the duties and responsibilities of lift personnel as specified by the American Society of Mechanical Engineers (ASME B30.5), and utilizing both knowledge and experience regarding crane safety programs/plans to provide a detailed account of the causal factors for crane accidents. The researcher's goal for carrying out this study was to provide a detailed account of the causal factors related to crane accidents. Utilizing data collected by this researcher doing analyses of 701 crane accidents over a 30-year period, the researcher seeks to enhance all fields of construction, particularly the crane industry, by providing valuable information regarding why crane accidents occur and recommendations regarding crane accident prevention.

1.2 Motivating Cases

The researcher spent the first years of his professional career working in a family construction business. The researcher has owned and operated cranes and this experience instilled great respect for the lifting processes and enhanced his knowledge regarding hazards associated with cranes. A desire to improve crane safety operations was advanced further during the researcher's subsequent years as a forensic engineer. As a forensic engineer, he has analyzed a continuing series of crane failures. Beginning in the late 1980s, the researcher has collected data during forensic evaluations of more than 1,000 crane accidents and has analyzed crane safety issues which led to those accidents. The researcher's interest in this topic has also been enhanced by Don Dickie's research, the San Francisco crane tower collapse, and much more (as noted below).

1.2.1 Don Dickie Seminar

In 1987, the researcher attended a Construction Safety Association of Ontario (CSAO) seminar during which Mr. Don Dickie provided details and data related to crane accidents, having collected that information during a study in 1983. During the seminar, Mr. Dickie detailed procedures based upon the findings of his comprehensive research study which could improve crane safety standards. The ability to identify key issues that contribute or cause crane accidents and the ability to address them by reinforcing simple procedures is effective and realistic plus it was an intriguing approach to risk analysis.

Mr. Dickie is a world-renowned leader who possesses expert-level knowledge related to cranes and crane safety. Dickie has published three books regarding cranes, rigging, planning, and responsibilities associated with the implementation of crane safety guidelines. These publications are entitled the *Crane Handbook*, the *Mobile Crane Manual*, and the *Rigging Manual*. Based on his research studies, Dickie reported during the seminar that more than 50% of crane accidents in Canada had occurred because outriggers were not deployed. Dickie emphasized that by mandating all cranes have outriggers fully extended prior to initiating any lift, there probably would be a great reduction in the numbers of crane accidents. The use of known, precise data and employing procedures neither complicated nor restrictive would eliminate many crane accidents. This simple fact inspired this researcher to use data regarding crane accidents collected throughout the years, to determine reasons why accidents occur and to offer guidelines to prevent future accidents.

1.2.2 Tower Crane Collapse San Francisco

On November 28, 1989, in San Francisco, a tower crane collapsed during a jacking sequence. This collapse resulted in 5 fatalities and 22 injuries (fatalities of 4 workers and 1 pedestrian; injury information is not segregated according to group type). As a result of this tragedy, the Construction Division of the American Society of Civil Engineers (ASCE) appointed a Task Committee to examine and comment on construction site crane safety. The Task Committee focused on the following: 1) crane design, 2) crane manufacturing, 3) transportation, erection, and the dismantling of cranes, 4) training and licensing of operators/riggers, 5) supervision and management of crane operations at construction sites, and 6) responsibilities of project owners or public agencies, the consultants, general contractors, crane manufacturers, crane owners, lessees, and regulatory agencies (Sale 1998).

That ASCE Task Committee, analyses and the OSHA investigation determined that workers involved in the tower crane jumping process (i.e., when height of a tower crane is extended) had neither formal nor informal instruction or other directives as to their individual duties or job tasks (OSHA, Report May 1990). Insufficient and even an absence of instruction or other directive on crane sites has not been uncommon in the crane industry. In this instance, however, due to the loss of lives and the multiple injuries that resulted from this San Francisco tower crane collapse, the lack of adequate instruction (i.e. what are your responsibilities?) provided to personnel working with the crane became an important area of focus for the ASCE Task Committee and a solid foundation for research development.

These findings by OSHA and the subsequent ASCE evaluation regarding this issue were published many years after Mr. Dickie had introduced the ambiguity/lack of knowledge associated with worker duties and responsibilities. Mr. Dickie's crane publications were available in the early/mid 1970s and identified those personnel and their responsibilities necessary to assure effective and safe crane lifts. Unfortunately, despite assessments by Dickie in the 1970s and the tragedy of the 1989 collapse, it was not until 1998 that ASCE published a list of the duties and responsibilities for all parties involved in crane lifts as part of the Task Committee report. Subsequently, the American Society of Mechanical Engineers (ASME) published ASME B30 - *Safety Standard for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks, and Slings,* a national consensus standard. ASME B30.5 – *Mobile and Locomotive Cranes* in 2007 listed personnel duties and responsibilities. Understanding processes of risk identification, crane accident cause determination, and the assignment of tasks/duties to personnel which address those issues, forms the foundation for this research study.

1.2.3 ASCE Report 93

The American Society of Civil Engineers (ASCE), supports efforts in the construction industry to promote and specify safety improvements. Sale et al. (1994) notes that the goals of the policy created by the ASCE includes the following:

1. Protect the public during crane operations.
2. Assigns the Contractor the primary responsibility for construction site safety, specifically including the management of crane operations.
3. Require the Contractor to develop site safety plans including a Crane Safety Program.
4. Encourage manufacturers to standardize load chart formats and equipment control configurations, with all manuals written in the language and vernacular of the end user in addition to SI units and containing detailed explanatory graphics.
5. Establish a program of crane operation certification that meets the following criteria:
    a. National in scope and implemented by the private sector
    b. Industrial relations neutral
    c. Re-certifiable, renewable, equipment specific with periodic testing
6. Recognize the critical role of the rigging function in the safe operation of cranes and clearly define rigging responsibilities.
7. Introduce training in crane safety management for Contractors staff and job site personnel.
8. Encourage the inclusion of courses for the safe utilization of cranes and rigging in College and University Civil Engineering Construction and/or Continuing Education Programs.

ASCE Manuals and Reports on Engineering Practice No. 93, *Crane Safety on Construction Sites,* identified the parties who are integral to crane lifts and specified that these individuals must be trained to plan and conduct crane lifts in the safest manner possible. Furthermore, the ASCE encouraged institutions of higher education to create college level courses, in the field of in Civil Engineering, which are dedicated to the management of cranes, as well as address the proper steps associated with rigging safety. The development and implementation of crane programs are an integral element in controlling, directing, and successfully completing a safe crane lift. Critical hazards addressed in a crane program must be understood and followed. The ASCE publication was the first in-depth analysis of duties and responsibilities in the United States and served as a model for ASME and their ultimate production of the standard.

1.2.4 Intricacies of Crane Lift Operations

Cranes, both mobile and static, are mechanical devices that rely on leverage and balance between the loads and the counterweight to lift, move, and place those loads. Cranes are used in virtually every industry around the world and are critical and indispensable tools for the dynamic and continually changing nature of construction. Despite the utilization of cranes in almost all industries around the world, humans operate those cranes, meaning that human intervention is necessary to rig loads, signal crane maneuvers, operate the crane itself, and carry out safety measures which ensure that tasks are completed properly. Proper lift planning requires the person directing the operation understand lift risks, know how to address potential hazards, and communicate that knowledge regarding risks, hazards, and safety requirements to members of the lift crew. Interactions among personnel involved in lifts requires planning, training, and collaboration. Each person must perform his or her duties and execute assigned responsibilities correctly. The 1989 tower crane collapse demonstrated how the lack of training and not understanding duties and responsibilities can result in tragedy.

Crane operations are unique because multiple parties, in addition to the operator, play integral roles in planning and conducting all aspects of lifts. Personnel are involved from the inception of a lift (e.g., planning, rigging, and conducting) to the completion of the lift process. When crane intricacies are ignored and feedback from individuals is not evaluated, accidents often result. Understanding all elements, responsibilities, and risks of a lift are necessary in determining causes of crane accidents.

The National Safety Council's (NSC 2009) publication titled the *Accident Prevention Manual for Business & Industry* (13^{th} ed.), has attributed 90% of mobile crane injuries to "operator error" despite the fact that it provides no definition of operator error (Neitzel et al. 2011). Additionally, the Thomas-Howell Group (based in London) regularly investigated crane accidents worldwide. The Thomas-Howell Group revealed that more than 80% of the 70 crane accidents investigated over a three-year period, were operator error (Sale et al. 1998). Attributing the majority of crane failures to operator error has led to repeated failures to conduct in-depth examinations of the fundamental causes of crane accidents. Furthermore, by failing to understand detailed reasons for these failures accidents continue to occur (Neitzel et al. 2001). By analyzing the conduct of parties responsible for crane accidents, a procedure previously not carried out, the researcher has been able to associate causes of these accidents based on documented responsibilities. This procedure has included evaluations of assigned and documented responsibilities and assisted in creating much safer worksites.

1.2.5 Crane Study Evolution

Over a period of 30 years, the researcher has analyzed more than 1000 crane accidents and accumulated specific data compiled from those accidents to analyze accident details and develop evaluations of contributing factors. Specifically, the researcher has examined the effectiveness of assigned duties and responsibilities of parties involved in crane lifts. The researcher has qualified in both state and federal courts as an expert in crane-related accident causation analysis. Furthermore, the researcher has been offered as a testifying expert for over 130 trials in the United States, to present his knowledge and expertise regarding crane-related accidents analysis and to assist in explaining all aspects of crane accidents.

The researcher also has worked as a member of the national consensus standards committee (ASME B30) and certification program development with the National Commission for the Certification of Crane Operators (NCCCO) for Operators, Riggers, Signalpersons, and Lift Directors. The researcher possesses recognized crane accident analysis knowledge/experience and a strong understanding of the development of national consensus standards and certification programs. These skills have provided a unique insight regarding accident causations, particularly the interactions of parties involved in these accidents.

Accident data initially were accumulated using standard forensic accident analysis techniques for causation determination. The data included physical characteristics of the sites, crane, load and rigging, weather, location (i.e., address, city, and state) and time of the incidents, all standard background information. Ultimate development of primary and secondary study attributes (essential key information) evolved over time and included all potential accident scenarios. Input from Subject Matter Experts from the crane industry also has been included. Crane accidents were evaluated both immediately following the incident and, in some cases, months, even years later. Timing resulted in the accumulation of different types of key information when there was no site inspection. Before including information regarding some particular incident, the researcher applied previously developed procedures which addressed a minimum number of primary sources of information. Detailed discussions of crane study attributes are included in Chapter 3.

Analyses of some incidents have required several years of information gathering; other incident analyses were completed quite quickly. As of January 1, 2018, there have been more than 1,000 crane accidents analyzed during the 30-year period of this study. One hundred and twenty of the evaluations have been set aside since adequate information could not be developed to meet an acceptable level of evaluation. Seven hundred and one (701) evaluations are complete and incorporated within this study. The remaining data, not included in the 701 cases analyzed, are at various stages of information gathering.

The analysis of data gathered during crane accident evaluations over the 30-year period is a unique and strong method for developing crane safety plans, determining realistic risk assessments, and carrying out necessary safety training based on appropriate analytic evaluations. A thorough analysis of compiled data (database) provided a proactive approach to identifying the diverse spectra of associated hazards common elements/factors that have contributed to these crane incidents. Implementation of corrective actions can be more precise and detailed based on the large number of similar accidents evaluated.

1.3 Vision and Research Questions

The researcher has sought to accumulate accurate information regarding specific crane accidents and the causes of those accidents using a methodology consistent with provisions of ASME B30.5 standards (developed in 2007) regarding the duties and responsibilities of personnel associated with crane operations at jobsites. By compiling this information into a large comprehensive database, the researcher hopes to provide information that will permit and encourage further analytical exploration of crane related accident information. Available information currently is incomplete with regard to causation, duties and responsibilities. Research questions (provided subsequently) guided the researcher while analyzing the available data, and also accounts for the gap in research regarding crane accident causation, as well as the need for additional research exploration.

1.3.1 Research Question 1

RQ1: Do the duties and responsibilities established by ASME B30.5 appropriately address associated causes of crane accidents by all responsible parties?

This first research question seeks to determine whether duties and responsibilities listed in ASME B30.5 address all causal factors that have contributed to crane accidents. While analyzing and examining crane related accidents, the researcher has determined that very few accidents have been due to direct mechanical failures and/or manufacturing defects. In fact, of the 701 crane related accidents reported in this study, only seven percent were due to mechanical/manufacturing issues. The other 93 percent were due to lift crew or jobsite personnel mistakes.

The ASME 30.5 (2007) document, approved and adopted more than ten years ago, has served as a guide to assist personnel in implementing proper procedures and protocol by which to mitigate inherent risks on the job sites. To ensure proper analysis of the data in order to answer RQ1, the researcher compared the assigned responsibility failures which led to each accident with the standards created by ASME. This comparison process evaluated the completeness of the standard and led to identifications, based on study findings, of other parties potentially responsible.

In addition to creating RQ1, the researcher has developed a sub question related to study findings that suggests additional responsible parties and responsibilities.

RQ1A: Should the list of duties and responsibilities be amended to include additional parties and corresponding responsibilities? Research findings identified several repeatable causative factors that suggest addition to the current responsibilities are warranted. Particularly, where consistent injuries have arisen during a specific lifting procedure.

1.3.2 Research Question 2

RQ2: How can the use of crane accident causation factors assist and improve the development of more effective risk management strategies to improve crane safety?

The large database compiled by the researcher provides extensive information regarding the specific causes of the analyzed crane accidents. This large database provides consistency and improves data integrity when an analyst is performing evaluations of specific causes of crane accidents. The evaluation of a single accident provides information based on that particular event; analyses of multiple similar accidents, under varying conditions, can help in the identification of common risks that otherwise might have been overlooked by crane accident investigation personnel. Evaluation of this large database provides great insight into initiating and contributing factors and into key risk factors and potential trends associated with crane accidents.

1.4 Scope of the Study

The researcher has compiled data during a 30-year period into a single Microsoft Excel document. This document includes information reported by forensic analysts regarding 701 crane accidents. Subsequently, the data was imported into SPSS for final analyses. Each accident analysis involved 57 specific items of input, as listed in Appendix A. These 57 specific items of input are in addition to evaluations of other issues that caused or contributed to each incident. Through utilizing multinomial regression, the researcher has identified key risk areas and patterns in the data, thereby exposing common factors which contribute to crane incidents.

Incorporated statistical data identifies parties responsible for crane accidents and compares the causes of the accidents to the list of duties for involved personnel in lifting operations as prescribed by ASME B30.5. The researcher developed a theoretical lift plan by identifying all parties involved in lift planning in order to understand the multiple personnel that are involved in planning and execution of a lift. Based upon a comparison of the statistical significance of the independent variables in the multinomial regression and the risk ratios, the researcher has identified several additional areas of responsibility that have been directly causative of crane accidents. These additional areas of responsibility currently are not included in the ASME B30.5 standard.

A second examination of the data involved searching for causes of those accidents which resulted in the greatest number of injuries and fatalities and association of the responsible parties. The most frequently encountered initiating and contributing causes of accidents were categorized in order to document high-risk factors, both initiating and contributing. This information categorization procedure limits or eliminates misidentified accident causation factors and assists in the development of training programs.

1.5 READER'S GUIDE TO THIS DISSERTATION

This dissertation has five chapters. Chapter 1 provides general information regarding the topic being explored, what has motivated this topic exploration, the research vision, and associated research questions. Chapter 2 explains the background literature, including peer-reviewed journal articles, trade publications, and books to provide the reader with a thorough understanding of cranes, crane legislation, causes of crane accidents, and gaps in the crane literature. Chapter 3 offers details regarding methodology used to analyze the data. Chapter 4 discusses the research findings and information regarding the various statistical analyses of the study's research questions. Chapter 5, the final chapter, lists conclusions and recommendations for future research.

Chapter 2 – Inherent Risks in the Crane Industry: A Risk Generation and Control Model

Chapter 2 presents information regarding the inherent risks associated with crane operations, crane accident data available in the industry, current training and programs offered to Crane Operators/personnel to mitigate future risks, and a theoretical overview of the process of lift plan development. As noted in literature, one of the most critical and often most dangerous aspects of construction projects involves lifting materials and equipment.

Multiple trades are involved in rigging, signaling, and operating cranes in order to achieve successful lifts. To properly train personnel associated with lifts, reliable information and processes must be disseminated to highlight the roles of all individuals involved in lifting operations. Although the general practice of planning, rigging, and lifting a load is similar in virtually all industries, site conditions and training processes vary between industries.

2.1 Hazards of a Changing Work Environment

In 2001, Neitzel, Seixas, and Ren of the University of Washington (UW), published a journal article titled *A Review of Crane Safety in the Construction Industry*. This publication provided information regarding crane-related injuries, available safety devices to prevent accidents/injuries, and other information regarding commonly utilized crane safety procedures. Authors of this journal article concluded that construction work differs from work in industrial settings in that construction workers often encounter challenges and dangers that change as the project progresses. It is common within a typical industrial setting for workers to experience the same environment and hazards on a daily basis; however, a construction worker may work for multiple employers and on multiple contracted projects. These changes increase job complexity. Neitzel et al. (2001) reported that crane accidents are common on construction projects and that as many as one-third of all construction and maintenance fatalities and injuries involve cranes. Without accurate information and data regarding risks that cause or contribute to these accidents, the success of any crane safety program is diminished. By conducting a thorough analysis of hazards attributable to accident causation, more effective and more concentrated efforts become available which should reduce the occurrence of crane-related accidents. Despite the high fatality and injury rates in the construction industry, Veazie et al. (1994) identified a scarcity of epidemiological construction research and highlighted that there are even fewer studies which specify the causes of crane-related accidents.

The identification and assessment of hazards and risks in any work environment is an essential first step in safety management (Brown 1976; Goetsch 1996; Holt 2001). However, differences between construction sites and industrial/manufacturing facilities dictate specialized methods of assessing hazards and risks at construction sites (Rozenfeld et al. 2010). Construction sites are dynamic (Bobick 2004) with many unique factors. Construction sites change continuously in topography, topology and work conditions throughout project duration (Rozenfeld et al. 2009). Additionally, construction projects experience frequent work team rotations, exposure to weather conditions, and high percentages of unskilled and temporary workers. These site variables tend to make managing site-safety more difficult than managing manufacturing plant safety programs (Rozenfeld et al. 2010). Timing the application of specific site safety measures in direct response to risk levels (Sacks et al. 2005) are critical when specific expected risks are about to develop (Rozenfeld et al. 2006). Long-range safety planning on most job sites can become generic over time due to repetition. In contrast, crane lifts are normally planned events typically scheduled to correspond to the task.

Jarasunas (1984a; 1984b) has studied causes of and ways to prevent crane accidents. In his 1984 study, Jarasunas cautioned against relying too heavily on placing reliance on cooperation and training of the employees to accomplish accident prevention. Further, Jarasunas (1984b) concluded the best way to make equipment as safe as possible is by means of technological advancement.

Data reported initially in this researcher's study indicate that 93% of those crane accidents analyzed involved some type of direct human error. Furthermore, preliminary analyses have reinforced a general conclusion that caused a majority of the crane-related accidents have personnel other than the Crane Operator (i.e., Lift Director, Rigger, Signal Person, and Site

Supervisor). Of the accidents caused by human error, operator error resulted in 26% of the accidents. Other crane personnel (i.e., Lift Director, Rigger, Signal Person, and Site Supervisor) caused 67% of the accidents reported while the remaining 7% are mechanical related. Although advancements in technology can assist in reducing some potential operator error issues, proper project planning can yield immediate and strong dedication to training those persons not at the crane controls (i.e., Lift Directors, Riggers, and Site Supervisors). Coordination between Operators, Lift Directors, Riggers, and Signal Persons are crucial. Given the findings that only 26% of crane-related accidents were caused by operator errors, it is clear that while the Crane Operator does control the load during a lift, there are many others involved in a lift who can have adverse effects on success of lifts.

Technology cannot address the ever-changing environmental factors that impact lifts. Each lift is different and is influenced by varying factors that are continuously changing. These changing environmental factors are particularly true when a Service Provider is involved in a crane project. (ASCE defines a Service Provider as the party responsible for bringing the crane and operator onto the site and controlling crane operations.) A Service Provider (or crane rental company) is exposed, in many cases, to constantly changing work environments and more important, lifting crews (i.e., Lift Directors, Riggers, and Signal Persons), that change with each lift and sometimes with industry sectors. It is the responsibility of the Lift Director to conduct pre-lift meetings and discuss the roles and responsibilities of all parties prior to lift initiation. The Crane Operator employed by a Service Provider must rely on other site personnel to analyze properly the lifting procedure, to determine weight of the load, to select and install, to direct rigging methods which assure load stability, to signal (guide) the operator around obstruction(s) for final load placement; and to ensure the landing area is both stable and structurally capable of supporting or bracing the load to be placed.

Preliminary study results suggest that since implementation of the Crane Operator certification (in 1995), operator-caused crane accidents have declined steadily. While this finding may be crane-related to factors outside of the scope of this study, it appears that there is a correlation between training received and decreased lift accidents. As technology continues to advance, training and certification offerings must keep pace with new hazards that can arise due to technological advancements. Although the role of the operator remains critical to the ultimate success of any lift, parties other than the operator are responsible for background preparation, lift development processes, and other aspects of the lift.

Crane accidents cause property damage, injuries, fatalities, and garner negative publicity (Hinze and Russel 2006). Job Safety Analyses (JSA) and Job Hazard Analyses (JHA), anticipation, and hazard avoidance can reduce greatly the likelihood of accidents. The analysis of specific job tasks using JSA/JHA procedures help integrate accepted safety and health principles and practices into specific tasks and job operations, including crane lifts (Rozenfeld et al. 2010).

A JSA is based on three parts: 1) job step; 2) hazard; and 3) control (Markiewicz 2009). Each basic step of a job must be detailed; hazards must be identified, and controls must be implemented to address the hazards/risks. Unfortunately, JSAs often become mechanical and routine, particularly because so many of the tasks are discussed repeatedly. In some instances, JSAs are applied for long periods of time (e.g., during erection of steel framing of a large building). Although unique practices and environmental conditions develop throughout the duration of a project, the same JSAs remain in effect since these JSAs address the overall safety analysis. For example, if a steel erection company has a JSA in place for erecting steel during windy conditions, that standard is applied. However, when winds are high, standard applications are not discussed and a disconnect between operator/project personnel develops. If JSAs are utilized, it is important that they be understood and applied to meet the situation actually at hand. Too often, though, JSAs are lumped together to address issues rather than to account for factors that necessitated JSAs be used.

The importance of JSAs and JHAs cannot be over-emphasized. It is incumbent upon safety and lift planning personnel to analyze and address serious hazards. A drawback of existing methods of risk assessment in construction (Jannadi and Almishari 2003; Yi and Langford 2006; Wang and Boukamp 2007) is that they do not account explicitly for the fact that on construction sites, workers not only endanger themselves and other workers, they also may endanger others not involved in the work (Rozenfeld et al. 2009). The basic situation remains as expressed by MacCollum (1993):

> Serious injury or death that occurs repeatedly from similar circumstances should be considered epidemic. These occurrences should be examined to identify hazards so that appropriate hazard prevention measures can be initiated in the same diligent manner that the medical profession examines a disease or infection to develop a vaccine or antibiotic for its prevention or control (p. 1).

2.2 AVAILABLE DATABASES

Since 1971, OSHA has collected data obtained through inspection procedures and reports of accidents associated with fatalities and injuries. OSHA has categorized this information and has analyzed raw data to assist safety professionals, as well as industry leaders, to understand why accidents occur as well as to develop training programs to prevent future accidents. Accident prevention is the most effective when based upon the issues experienced during prior events. Accidents increase awareness and proper evaluations can provide further understanding of what went wrong/what caused an accident. Understanding what caused an accident is critical in ensuring that implemented measures and initiatives (i.e., training and protocol implementation) will prevent future accidents (Beavers et al. 2006; Hinze and Russell 2006).

OSHA's data, incorporated into the Integrated Management Information System (IMIS) database, has been the primary (if not sole) source of accident studies throughout the past three decades. IMIS data has limitations since it reports only fatalities and serious injuries. Less severe injuries (injuries that do not involve hospitalization or lost work time) and property damage are not reported by OSHA to IMIS. IMIS input provides the following information about each incident: location, date, Standard Industrial Classification (SIC), type of citation, abatement status, amount assessed for the penalty, a brief description (e.g., abstract) of the accident, information about the injured worker (i.e., age, severity of injury, sex, etc.), and factors contributing to the accident (i.e., environmental conditions, hazards, and human factors). As noted by Hinze and Russell (2016), while the database includes information from all workplace industries, it does not specifically identify accidents associated with cranes and lifting. The system is set up to provide information of value only to OSHA. As a result of missing information, the data cannot be sorted easily, and those responsible for input are not trained to input consistently the properly coded information into the system (Hinze and Russell 2016). OSHA utilizes over 450 codes to report accidents, thereby increasing greatly the difficulty of proper coding. This difficulty is compounded further because no two codes are the same, and all codes are complex.

Although pertinent information is available through IMIS regarding causes of injuries, the information is too generic to offer meaningful data to assist in developing and determining accident prevention programs (Hinze et al. 1998). Information collected by OSHA compliance officers generally consists of a brief narrative of the incident with some recorded in assigned code categories. The five categories most commonly used by OSHA compliance officers highlight the following types of accidents: falls, struck-by, caught in/between, electric shock, and other. These code descriptions are simple but do not describe the root causes of the accidents. Furthermore, these codes are too broad in scope to describe clearly the specific causes of accidents and many accidents cannot be described clearly based on this restricted code system (Hinze et al. 1998).

In a 1997 study, Suruda et al. described two main limitations associated with of OSHA data. The first is that the numbers of OSHA-investigated crane-related deaths in construction is unknown. Furthermore, details available for analysis in the OSHA report summaries are varied. Sometimes, the electronic reports provided by OSHA are incomplete. A second limitation of the OSHA data is that the electronic summary reports vary by types of incident. For instance, reports of deaths involving crane assembly or disassembly do not include crane specifics (i.e., a hydraulic crane, a lattice-boom crane, or a tower crane).

Shapira and Lyachin (1997) suggested not utilizing OSHA’s statistical data because so many incidents go unreported, because the information does not include root causes of the incidents or statistics regarding accident prediction. The researcher of this study determined that statistics regarding construction accidents involving cranes could have been a reliable source of information for this study. Unfortunately, statistical information accumulated by OSHA failed to identify types of cranes involved in the accidents (i.e., mobile cranes, tower cranes, etc.). Shapria and Lyachin (1997) also found that crane accidents commonly were reported only in cases of fatalities or severe injuries. Sale et al. (1998) observed that numerous incidents simply were not included in the statistics, even those incidents reported by the companies responsible. Cases analyzed in this study may involve minor injuries or "only" property damages. Such incidents constitute the majority of crane-crane-related accidents, and the failure to include such accidents reduces greatly the information needed for the ASCE study. All in all, crane-related accidents are subject to gross under-reporting or reporting that lacks detail (Butler 1978; McDonald and Hrymak 2002).

Beavers et al. (2006) concluded that OSHA does not yet have effective tools, data entry forms, training programs, or quality control systems in place to help Compliance Safety and Health Officers (CSHOs) to code accident information consistently and accurately or to enter inspection data into IMIS. Furthermore, there is little formal guidance for CSHOs to write abstracts effectively or to capture key factors that may have contributed to the fatality or injury. Data gathering process gaps/issues create voids in the reported information, and there is no standardized narrative utilized by the CSHOs. Beavers et al. (2006) concluded that the primary purpose of OSHA investigations was to determine what standards were violated, not to determine the causes of the accidents.

2.3 Use of Experts for Accident Analysis

While the IMIS statistical data provides limited information regarding the root causes of accidents, data available regarding crane accident specifics remain incomplete. Fatality statistics not classified according to industry sectors or types of cranes involved in accidents are all that is available to researchers. For data analyses of crane accidents to be detailed and reliable, it is necessary that a large database with in-depth information/data be provided regarding initiating and contributing causes of crane accidents. Past crane accident researchers have encountered similar problems of limited data and have turned to experts in the field to develop information concerning hazards (Cho et al. 2002; Lee and Halpin 2003). Harms-Ringdahl (2001) and Rozenfeld et al. (2010) maintain that questioning experts about particular procedures or processes is a viable option when no data is available. Obviously, viability demands that experts consulted possess strong knowledge attained through education and extensive field experience. Unfortunately, root cause data regarding crane accidents is limited or not even available. This dearth of root cause data limits determinations of whether accidents resulted due to failures of personnel to follow recommended procedures or due to equipment problems.

The term accident does not mean that an injury occurred. In fact, accidents can destroy equipment and materials, and cause project delays, recovery costs, and unwanted negative publicity. Hinze et al. (1998) explained that individuals often pay much closer attention to accidents that cause injuries or deaths. It is critical that professionals planning crane lifts possess the knowledge, skill, and ability necessary to identify those risks which might develop thereby ensure proper implementation of safety protocol. While organizations continue to implement safety strategies, technological advancements/developments have led to increased numbers of occupational incidents, many of which have had severe consequences (Hamid and Majid 2008).

Every industry has unique approaches when determining Crane Operator training requirements. Furthermore, given technological advancements and field changes, it often is n difficult to hire Crane Operators who are knowledgeable of field changes, compliance standard improvements, and so forth. The demands associated with larger loads, greater reaches, and precise load placement have mandated crane manufacturers constantly upgrade machine capabilities and provide innovative technological advancements for their equipment. The introduction of Finite Element Analysis (FEA) techniques has enabled designers to refine their designs by identifying high stress areas and modifying their designs to address high stress areas. Similarly, areas with lesser stress levels can be reduced in size. The overall effect of FEA processes has been a reduction in equipment weights and increased performance. For example, the Construction Safety Association of Ontario has demonstrated that as a result of crane design refinements utilizing FEA, a crane once rated at 30-ton capacity during the 1960s now has a 50-ton lift capacity rating, thus reducing overall weight of the equipment.

Crane design innovations, have increased lifting capacities and reach capabilities, enabling designers to develop increasingly complicated structures. Design modifications have led to the development of extremely large cranes (mega cranes). Advancements made by Deep South Versa-Crane, Lampson Transi-Lift, and other massive lifting equipment allow industries to accomplish what previously was considered impossible. Land-based cranes, with booms longer than 600 feet and capacities of 2,500 tons and greater, have become available. Given advancements and modifications, designers and developers of these mega-cranes have created specific training programs focusing on proper handling methods for large loads and extended reaches. Training for handling large loads at extended reaches are not limited to Crane Operators but are also available to the entire lifting crew and management team. In order to ensure correct maintenance and to uphold safety standards, it is most important that Crane Operators have earned proper certifications and the training necessary to operate these large cranes (MacCollum 1993; Neitzel et al. 2001). Further, in order to promote crane safety, similar certification programs have been developed for Lift Directors, Riggers, and Signal Personnel.

2.4 Regulatory and Voluntary Crane Standards

Crane design and crane operations are governed by both regulatory and voluntary standards. These play different roles in the crane industry (Neitzel et al. 2001). Regulatory agencies disseminate and enforce standards specifying minimum requirements for crane safety operations. Conversely, voluntary standard organizations, such as American National Standards Institute (ANSI) and ASME B30, promote qualities of excellence exceeding minimum requirements set forth by regulatory agencies such as OSHA. In 2010, OSHA amended the crane standard with the addition of 29 CFR 1926.1400. This amendment followed several years of discussion/input provided by the Crane-Derrick Advisory Committee (C-DAC).

One of the primary amendments to 29 CFR 1926.1400 was addition of Crane Operator certification. With the issue of this OSHA amendment in 2010, all Crane Operators were required to obtain Crane Operator certification by a recognized organization such as the National Commission for the Certification of Crane Operators (NCCCO), by November 10, 2014. Since issuance of this amendment, the deadline to obtain this certification has been extended several times. In fact, the most recent certification deadline is November 10, 2018. In part, these extensions have come about due to differences between OSHA and crane industry definitions of operator classifications. During the public review process of the new 1926.1400 amendment, OSHA required that operators be certified for every type of crane that they might operate. NCCCO and other organizations, as well as industry leaders, considered the addition of the 1926.1400 amendment to be burdensome. The opposing argument to OSHA during the appeal of the new amendment was that crane type (i.e., crawler, hydraulic, lattice boom, mobile, and tower) should be one criterion, and that tonnage and the size of the cranes also should apply.

The American Society of Mechanical Engineers (ASME) created the B30 Standards Committee, a voluntary consensus national standard organization comprised of 32 sub-committees/groups. The most commonly referenced section of the B30 standards, B30.5, is entitled *Mobile and Locomotive Cranes.* This section applies to all mobile cranes used in all industries. In response to improving crane safety, in 2007, B30.5 was amended to include information regarding duties and responsibilities of personnel involved with crane lifts.

The final responsibility section of B30.5 closely mirrored what originally was proposed by the Construction Safety Association of Ontario and ASCE Report 93. The original proposal, written by Dickie, evolved from a study concerning Canadian crane accidents. It included a thorough risk assessment and has resulted in the identification of roles and responsibilities for every member of the lift party.

2.5 Operator Certification

Training and certification must be ongoing endeavors. Continuation is important to assure individuals remain aware of diverse and technically complicated crane designs and possess familiarity regarding the complexity of current regulatory and voluntary crane safety standards (Neitzel et al. 2001). Conventional training for safety and health personnel rarely addresses cranes and crane safety requirements. Additional college-level courses in Civil Engineering, as well as continuing education classes, promote better understanding of the complexities of cranes, lifts, and crane designs/operations (Sale et al. 1998).

Given the complexity of crane designs and operations and the difficulties associated with lifting loads at great distances, operators must know operational parameters/specifications for the crane they are operating. Throughout the years, it has become increasingly challenging to ensure that operators be trained to handle technological advancements in crane design and control (Neitzel et al. 2001). During the 1990s, the Specialized Carriers & Riggers Association (SC&RA) established the National Commission for the Certification of Crane Operators (NCCCO) to provide operator certification to address, among other things, advancements in crane technology. NCCCO assembled a team of experts to identify the operator knowledge necessary for safe crane operations.

To ensure operator knowledge met levels necessary, the NCCCO surveyed/tested experienced Crane Operators. This surveying process sought to confirm that Crane Operators understood both federal and consensus national standards and could read and understand load charts and operation manuals. Testing was segregated according to the various sizes of cranes and addressed increased complexities and differences between lattice boom type and hydraulic cranes. Once Crane Operators passed the written exam, they were required to complete operational tests to ensure they understood crane operations (in regard to crane size and type). When Crane Operators successfully completed both parts of the examination, they were awarded their certification by the certifying agency. Five years subsequent to earning initial certification, recertification would be necessary.

Recertification tests require operators to demonstrate continued operating proficiency. During February 1999, OSHA acknowledged the accredited certification process and signed a memorandum of understanding with NCCCO. OSHA has recognized that all certifications awarded by NCCCO comply with the new 1926.1400 crane standard. A study conducted by the University of Washington (UW) confirmed that the Canadian Province of Ontario had instituted a certification program in 1979 to ensure that Crane Operators possessed necessary competencies to operate cranes. Results of the UW study have confirmed that fewer crane-crane-related fatalities have occurred in the Canadian construction industry since the institution of this certification program. Reportedly, from 1978, the year in which the certification program went into effect, until 1995, the construction crane fatality rate decreased from 3.59 per year to 1.40 per year. The fewer fatalities provides evidence that the certification program has helped reduce the frequency of catastrophic accidents (Neitzel et al. 2001). Although the program had been created in Canada during 1979, it was not until 1995 that the National Commission for the Certification of Crane Operators (NCCCO) initiated the first crane certification program in the United States.

2.6 Crane Accidents and Human Interventions

Mechanical issues which cause crane accidents are fairly easy to identify (mechanical breakdowns, welding failures, etc.) and repairs or modifications must be coordinated through the manufacturer. An assessment of crane lift risks requires a complete understanding the effects that human intervention and decision making have in the success or failure of lift operations. According to Ridley (1986), 99% of all crane accidents are due to unsafe acts, unsafe conditions, or both. Examinations of national and consensus standards and of the causes of the 701 crane accidents, verified that the following parties and/or factors have responsibilities associated with lifts which influence success or failure: Crane Manufacturer, Crane Operator, Lift Director, Manufacturer of the Load/Lifting Instructions/Load Connection Points, Maintenance and Inspection issues, Other, Owners/Users, Riggers, Service Providers, Signal Persons, and/or Site Supervisors.

The original list of responsibilities derived from Dickie's research in addition to research and input from the ASCE and ASME. During the evaluation process, it became clear that there were factors crane-related to lift success or failure that were not under the direct control of personnel involved in the lifting process. In addition to the Crane Manufacturer, the manufacturer of the load being lifted led persistent problems of lost or unstable loads. Study results identified numerous incidents which occurred during the lift when the load suddenly shifted or rotated after being lifted. During trial lifts, rigging crews had to determine the center-of-gravity by making several rigging changes during trial lifts, and did not hoist the load lifts until it would not shift, rotate or flip. This was most common situation when mechanical equipment was being placed on roofs or at great heights in a mechanical room. The researcher of this study believes that manufacturing companies that produce a product which must be lifted or placed in tight quarters should provide detailed lifting instructions or install lifting lugs (points to attach rigging to the equipment). Reliance on field rigging personnel to devise effective rigging to balance a load by trial and error determination of the load center-of-gravity created unnecessary risks.

A second area of risk not covered currently by any responsible party, relates to crane inspections. Numerous accidents have occurred immediately following an annual inspection. Such accidents often occur when there are maintenance issues that go unattended (for example, improper brake adjustments, excessive wire breaks in the load or boom hoist lines, and even pre-existing weld fractures). Inspection firms must be qualified to perform critical conditional surveys and inspections to ensure the equipment will operate as intended by the manufacturer. Evaluations of these accidents have resulted in the assigned responsibilities, as noted in Tables 1 and 2.

Table 1: Responsible Party by Category

RESPONSIBILITIES VS CATEGORY	Commercial Construction	Highway Road & Bridge	Industrial Refining	Residential Construction	Logging Arborist Agriculture	Manufacturing	Marine Industry	Mining Industry	Oilfield Land-Base	Oilfield Offshore	TOTALS	Percentage of 701 Accidents
Crane Manufacturer	11	5	8	2	4	2	1	-	3	-	36	5.1%
Crane Operator	57	18	46	7	1	18	9	2	8	1	167	23.8%
Lift Director	37	13	39	6	6	3	11	2	10	6	133	19.0%
Manufacturer of Load/Lifting Instructions/Lugs	3	2	6	1	-	1	-	-	1	-	14	2.0%
Mainenance and Inspection Issues	7	3	5	-	-	9	4	-	3	3	34	4.9%
Other	4	1	6	-	-	1	3	-	1	4	20	2.9%
Owner/User	5	1	6	1	-	7	2	1	1	2	26	3.7%
Rigger	54	5	23	6	4	3	5	2	9	7	118	16.8%
Service Provider	7	-	3	-	-	1	1	-	1	-	13	1.9%
Signal Person	26	-	7	-	-	1	2	-	-	1	37	5.3%
Site Supervisor	33	14	30	-	-	5	7	6	7	1	103	14.7%
TOTALS	244	62	179	23	15	51	45	13	44	25	701	100.0%

Of the 701 accidents examined in this study, human interventions caused 651 (92.9%) of the incidents. Only 50 (7.1%) of the accidents resulted due to machine mechanical issues. These numbers demonstrate conclusively the importance of determining why these accidents have occurred.

Table 2: Total Crane Accidents: Human Intervention versus Mechanical/Design

Human Intervention	No:	Mechanical/Design	No:
Crane Operator	167	Crane Manufacturer	36
Lift Director	133	Manufacturer of Load/Lifting Instructions/Lugs	14
Maintenance and Inspection Issues	34		-
Other	20		-
Owner/User	26		-
Rigger	118		-
Service Provider	13		-
Signal Peson	37		-
Site Supervisor	103		-
Total-651 Accidents (92.9%)	**651**	**Total-50 Accidents (7.1%)**	**50**

Preliminary study results clearly indicate human error/intervention is the primary cause of crane accidents. By analyzing known human-crane-related factors which contribute to accidents, the industry will have a detailed guide which addresses potential risk factors, leading to increased project control and improved planning. By comparing known causes of accidents with the duties and responsibilities identified by ASME B30.5 (2007), effectiveness and accuracy of the standard can be evaluated. The gap in research has resulted because existing databases do not provide information required to evaluate effectively the hazards/risks for crane lifts. This limits evaluations which would improve lift planning and crane safety. For example, factors crane-related to mechanical and inspection issues ultimately were classified as human intervention issues because inspectors failed to identify problems with critical components of cranes during annual inspections. Despite annual inspections, malfunctions of crane components, which might have occurred in the period between inspections, or perhaps were overlooked during the inspection, have resulted in accidents and injuries.

In some instances, assigning duties and responsibilities to parties can be a subjective process. For example, there have been numerous instances in which more than one party was responsible for an accident. This multiple responsible party situation arose since the duties and responsibilities can be assigned to many individuals (see Table 3). In fact, in some cases, three separate parties have been identified as being primarily responsible for a single accident. The percentage of accidents associated with direct human intervention remains the same when multiple parties are identified as being responsible; however, some variations may exist due to isolated subjectivity in the assignment of responsibilities.

Table 3: Multiple Responsible Parties by Category

RESPONSIBILITIES VS CATEGORY	Commercial Construction	Highway Road & Bridge	Industrial Refining	Residential Construction	Logging Arborist Agriculture	Manufacturing	Marine Industry	Mining Industry	Oilfield Land-Base	Oilfield Offshore	TOTALS	Percentage of 701 Accidents
Crane Manufacturer	11	5	8	2	4	3	1	-	3	-	37	5.3%
Crane Operator	64	19	48	7	2	22	9	2	11	1	185	26.4%
Lift Director	48	17	55	7	10	4	14	3	13	6	177	25.2%
Manufacturer of Load/Lifting Instructions/Lugs	4	2	6	1	-	1	-	-	1	-	15	2.1%
Mainenance and Inspection Issues	8	4	5	-	-	9	4	-	3	3	36	5.1%
Other	4	1	6	-	-	2	3	-	1	4	21	3.0%
Owner/User	6	1	8	1	-	10	4	2	1	2	35	5.0%
Rigger	56	5	24	6	4	3	5	2	9	8	122	17.4%
Service Provider	10	-	5	-	-	1	1	-	2	-	19	2.7%
Signal Person	34	-	8	-	-	1	2	-	-	1	46	6.6%
Site Supervisor	47	22	45	-	-	6	8	9	8	2	147	21.0%
TOTALS	292	76	218	24	20	62	51	18	52	27	840	

The number of crane accidents reviewed increased as this research study progressed. In order to compare operator responsibilities, prior to and after inception of NCCCO, cumulative averaging was used to track the results. Each year, the number of accidents associated with each responsible party was compared to the total number of accidents evaluated. Cumulative averaging indicated apparent effectiveness that implementation of the operator certification program, in 1995, (Figure 1) had on accidents. Incident causations assigned as operator responsibility, prior to 1987, were omitted due to limited data availability.

Figure 1 illustrates that from 1995 to 2017, the frequency of operator responsibility for accidents has a downward trend, potentially indicating that more extensive training, as well as certification mandates may reduce operator-caused crane accidents. The percentage of operator caused crane accidents decreased greatly between 1995 and 2017. In fact, over the course of the study period, associated operator accident responsibility decreased to 23 percent based on the latest calculations listed in Table 3. When compared to being initially around 30% in 1995, the downward trend seems to demonstrate a substantial reduction in operator associated risks as a result of the certification process.

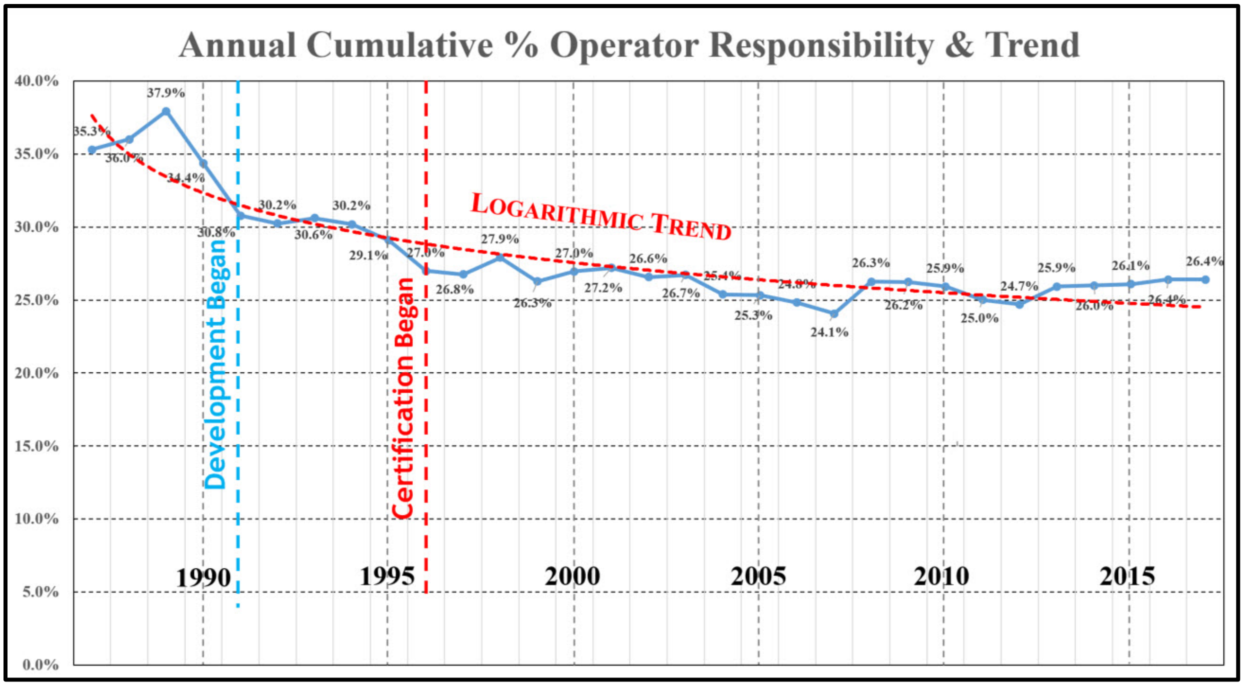

Figure 1: Operator Responsibility and Trend (1987-2017)

The statistics also demonstrate that the crane lift processes and resulting accidents are influenced heavily by human error. The Crane Operators certification process has shown the great potential for success and a corresponding reduction in operator-caused issues over the duration of the study. Currently, certifications are available for Riggers, Signal Persons, and Lift Directors, individuals who play key roles in lift processes. The Lift Director is a key individual who contributes to the success of a lift. The Lift Director coordinates the tasks of the other parties and ensures that specific procedures and responsibilities are followed. When examining a similar Lift Director Responsibility and Trend analysis, it is clear that the certification implemented in 2017 was warranted (Figure 2). Communication between the Lift Director and the crew (Crane Operator/Rigger) is paramount in ensuring that every specific duty is understood and carried out according to the plan. Failure to follow lifting requirements can, and often does, lead to accidents and consequent injuries and fatalities. Communication becomes more critical when new members join the crew, creating a personnel group that has not worked together previously.

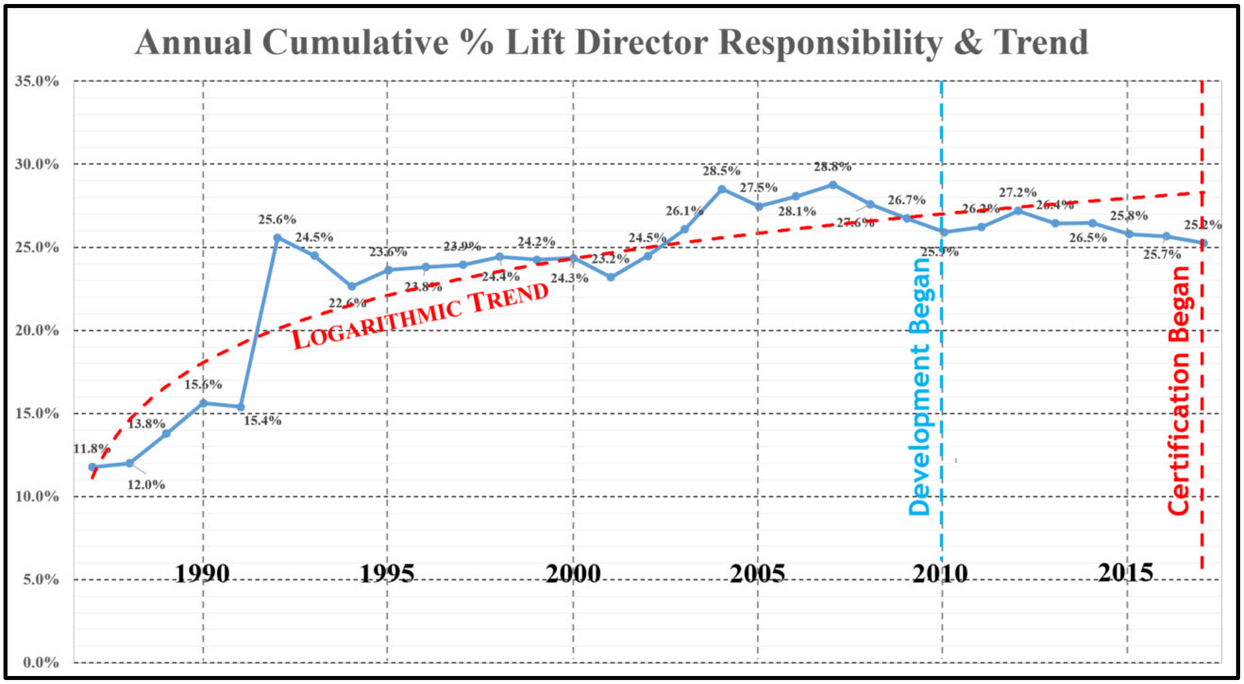

Figure 2: Lift Director Responsibility and Trend (1987-2017)

2.7 CHAPTER CONCLUSION

It is apparent that the increased responsibilities placed on the Lift Director to coordinate and direct lifting operations has had an impact on this position and the necessity for certification. The Lift Director must have extended skills as compared to other lift personnel. The slight reduction trend in Lift Director assessed responsibility for crane accidents has begun to slightly diminish since the announcement of certification for this position in 2010. Crane companies, Crane Owners, and Site Supervisors have become aware of the criticality of the Lift Director and have worked to assure those duties and responsibilities are being addressed

Understanding crane operations and the associated risks has been an ongoing endeavor for years. The crane industry has recognized that the operator cannot be responsible for every aspect of lift; however, those not directly involved in "pulling the levers" must be made aware of what is expected and required of each involved participant in safe lifting procedures. Identifications of those duties and training personnel to perform those duties will improve crane lift safety. Through training and certification lifting personnel have a more complete understanding of their role and requirements expected of them during the lift. The key is communication between all parties and collaboration of the parties to ensure lifting personnel function as a team rather than individuals.

Chapter 3: Assessing the Risks Associated with Crane Lifts: A Mixed Method Approach

The Construction Industry Institute (CII 2007) indicated that construction safety performance has stagnated to the point that only marginal improvements have been achieved. CII has researched the identification and analysis of near misses to help identify hazardous conditions and unsafe work practices before they occur. Further, communication was cited by CII as the greatest enabler, including feedback from workers that was found to enhance safety.

This chapter suggests an innovative approach that can be utilized to analyze crane hazards and accident causes based upon the identification of parties responsible for project errors/failures. Application of this technique should enhance accident prevention. As detailed in Chapter 2, human error caused 92.9% of the 701 crane accidents that have been analyzed, thereby reinforcing the importance of understanding human errors and failures. In addition to the influence of human error, in regard to crane accidents, investigators have identified that operator error has caused many crane accidents, which is an inaccurate conclusion.

Numerous personnel have been involved in procedures that required successful completion to ensure crane lift success. In order to understand all aspects of lifting operations, the researcher deemed it necessary to examine crane lift planning stages and to analyze the roles and responsibilities of all persons involved, as well as the contributions of each to the lift process (both primary or secondary). Don Dickie used a process of assigning duties and responsibilities of parties as part of accident analysis that was used by this researcher. This similarity allowed the introduction into this study of duties and responsibilities for crane personnel first introduced in the 1970s. During discussions with Mr. Dickie, this researcher learned that the approach utilized initially by Mr. Dickie was developed from feedback received from various trade union personnel, as well as from examining the corresponding training manuals used by union personnel.

Understanding the intricacies of crane lifts and the responsibilities of the associated workers is essential to any study geared to reduce the frequency of and potentially eliminate future crane accidents.

3.1 INTRODUCTION

Cranes are as unique and fascinating as the accidents which occur when crane operations do not go as planned. The purpose of this study has been to evaluate a broad cross section of accidents which have happened throughout the United States and accumulate information which will provide the crane industry with a reference which lists those factors which have caused accidents. Furthermore, by developing a broad understanding of these accidents. The researcher also has provided recommendations for assigning duties and responsibilities to personnel involved in crane lifts as another aid in preventing future accidents. The findings and recommendations presented within this study, it is believed, can be of great value to Crane Owners, users, manufacturers, and standards committees and will allow these groups to reduce crane related risks in the future.

Prior studies reviewed by the researcher relied almost exclusively on statistical data published by OSHA (IMIS). These data are useful but often omit crucial causation information. While conducting this study, the researcher reviewed more than 200 OSHA files, almost all of which lacked causation details. The purpose of OSHA investigations is to determine which regulations were violated within the employer/employee relationship, not to determine the cause(s) of accidents. In contrast, evaluations in this study are comprehensive analyses of accident causation.

In addition to reviewing OSHA investigation files and evaluating factors causative of the incidents, the researcher has analyzed the responsibilities of involved parties as identified in ASME 30.5 standard. Other available research does not differentiate between industries, instead they combine data into general use categories, thereby implying that crane applications are similar in all industries. During the analysis phase of this study, it became clear that there are considerable differences in crane lift applications between industry sectors. The researcher therefore has sought to provide information about crane related accidents in different industries and different applications and thereby offer a thorough evaluation of causal factors associated with all types of crane accidents.

3.2 Background Research

The researcher became interested in cranes at a young age while working in his family's construction business. The why's and how's associated with accident occurrences became increasingly important after his professional career in forensic engineering began. Furthermore, after being exposed to many types of crane accidents and evaluating the causes of those accidents, the researcher realized he wanted to share his experience and knowledge with the construction community. In order to share his experience, the researcher became involved in the national consensus standard development committee (ASME B30). He also assisted in the development of testing guidelines to be used by Crane Operators, Riggers, and Lift Directors through involvement with NCCCO. Ultimately, it became obvious to the researcher that the information being gathered during inspections, analyses, and reporting processes could benefit the industry if that information could be compiled into a comprehensive database.

Data derived during evaluations of the 701 crane accidents considered in this study became the basis of detailed accident causation analysis. The researcher examined all accident data utilized in this study and had teams of forensic engineers with crane industry expertise also evaluate the information. Information regarding each of the 701 crane accidents was screened to identify: the types of work being performed, the numbers and kinds of cranes being used, the lifts being performed, and the natures of the accidents that occurred (i.e., boom collapse, overturn, rigging failure, etc.). These evaluations identified accident causation factors and responsible parties in accordance with the ASME B30-2007 guidelines. While other data concerning crane-related accidents have been collected throughout the years, the researcher selected 701 incidents of comprehensive data analyses.

Crane accidents are costly, often disrupt scheduling, destroy equipment, and cause injuries and deaths. In this study, both monetary and human damages caused by these incidents were quantified. While working with Crane Owners, Crane Users, and manufacturers, the researcher realized that a primary goal of all parties in the crane industry was to eliminate catastrophic events and to protect workers and the public. The implementation of standards, training requirements, and governing bodies was the consequential result of that basic goal.

Cranes have served as a backbone in all industries that require lifting and moving loads of various sizes and shapes. When properly used by well trained personnel, the mechanical advantage provided by cranes improves greatly both productivity and safety. The research included in this study has evaluated crane accidents in all U.S. states except South Dakota (the researcher has not studied a crane accident and has not been involved with any projects in this state). Work in the 49 other states has provided a broad cross section of information. Unlike prior studies regarding crane incidents, the data used within this study are not limited to incidents involving only crane related injuries and fatalities. Instead, the data of this study covers injuries, fatalities, equipment damage, and property damage. The data also list responsibilities, a unique addition to the general information. Based on requests from Subject Matter Experts (industry experts), the data analyses also are segregated into OSHA regions to facilitate comparative analyses.

3.3 USE OF SUBJECT MATTER EXPERTS

Crane accident information collected and analyzed by the researcher of this study, includes details regarding site characteristics, witness statements, crane characteristics/configurations, and measurements detailing the crane location and operating radius. For larger accident sites, the information collection process included high-definition 3D laser scanning processes which recorded detailed information regarding overall characteristics of the site, debris location, surrounding hazards, and details of the lift plan layout. Additional information regarding company personnel involved with the lift was collected and analyzed to determine whether they had carried out their assigned duties and responsibilities in accordance with ASME B30.5-2007 standard. The collection of such extensive information ensured that sufficient detail was available to permit preparation of detailed reports of findings. These detailed analyses have identified many factors that may have contributed to causing accidents. With these additional factors identified, improved lift planning and safety analyses have evolved on the work sites.

Based on the background and experience in both operations and forensic analysis, the researcher established five essential elements of information (primary attributes) are crucial to every crane accident investigation. Analysts should make every effort to collect this information at every crane accident site, thereby to assure that sufficient information is available to conduct a complete analysis. The five major attributes (essential elements of information) comprised the following: accident data, crane characteristics, personnel responsibilities, project characteristics, and operational background.

Specific data collection efforts must accompany the primary elements of information. The researcher learned quickly that each accident first should be classified according to accident type. Types of accident information provides the starting point by identifying initiating and contributing factors of an accident. Random examinations of the preliminary data enabled the researcher to develop a list describing 15 different types of accidents, as noted below in Table 4.

Table 4: Types of Accidents and Explanation of Accident Characteristics/Factors

Accident Type	**Explanation of Accident**
Assembly/Disassembly	Crew was conducting assembly or disassembly of a crane
Boom/Jib Dropped	The boom or jib lost support and fell
Boom/Jib/Tower Collapse	Boom, job, or tower collapsed during operation
Crane De-Rail/Travel	Crane is traveling or upset
Crane Stability/Overturn	Crane lost stability and overturned
Landed Load-Stability	Load is landed on unstable structure or bracing
Lifting Personnel Basket	Incident occurs during which the lifting personnel is in a basket
Power Line Contact	Some part of the crane or rigging contacts a power line
Rigging Failure	A component of the rigging failed
Signaling	Improper signals disrupt the lift
Slewing Assembly Failure	Slewing assembly separates and fails
Trip/Fall/Jump from Crane	Worker trips, falls, or jumps from a crane
Two-Blocking	Load block or overhaul ball contacts boom tip sheave
Unstable/Dropped/Lost Load	A lifted load becomes unstable and drops from the rigging
Other	Other types of incidents

Prior to formulating final versions of the primary elements of information list and types of accident list, the researcher consulted with Subject Matter Experts (SMEs) with knowledge in manufacturing, service industries, contracting, insurance, labor relations, government requirements, and consulting groups, to take advantage of their experience with crane related accidents. SMEs were selected from ASME Committees, the NCCCO Committees, Service Providers (Crane Rental Companies), and Contractors. SMEs provided a wealth of experience and background and were located throughout the United States and Canada. The researcher collected responses from the SMEs through direct meetings and correspondence. The researcher requested that participants provide their evaluation, comments and recommendations regarding the following:

- Are the five primary attributes (essential elements of information) suggested in this study sufficient to evaluate conclusive causes of accidents? If not, please provide additional areas that should be addressed.
- Based on the five primary attributes (essential elements of information), what specific secondary information should be collected?
- Are there situations and conditions, in your industry, that are so unique that they should be included in this study?

The researcher evaluated participant responses and identified pertinent areas of interest/exploration, which thereby enhanced crane accident causation analyses. Based upon the recommendations made by polled participants, the researcher included 57 specific items of information regarding the accident to be inputted into the analyses. In addition to these items, a narrative summary of site-specific issues that caused or contributed to the incident proved very useful. All information entered into a Microsoft Excel spreadsheet was compiled to make available combinations of information and thereby enable users to focus on key risk factors. Each response was documented (verbally or by e-mail) and evaluated. The final outline of primary attributes and corresponding secondary attributes was compiled into the following flow chart:

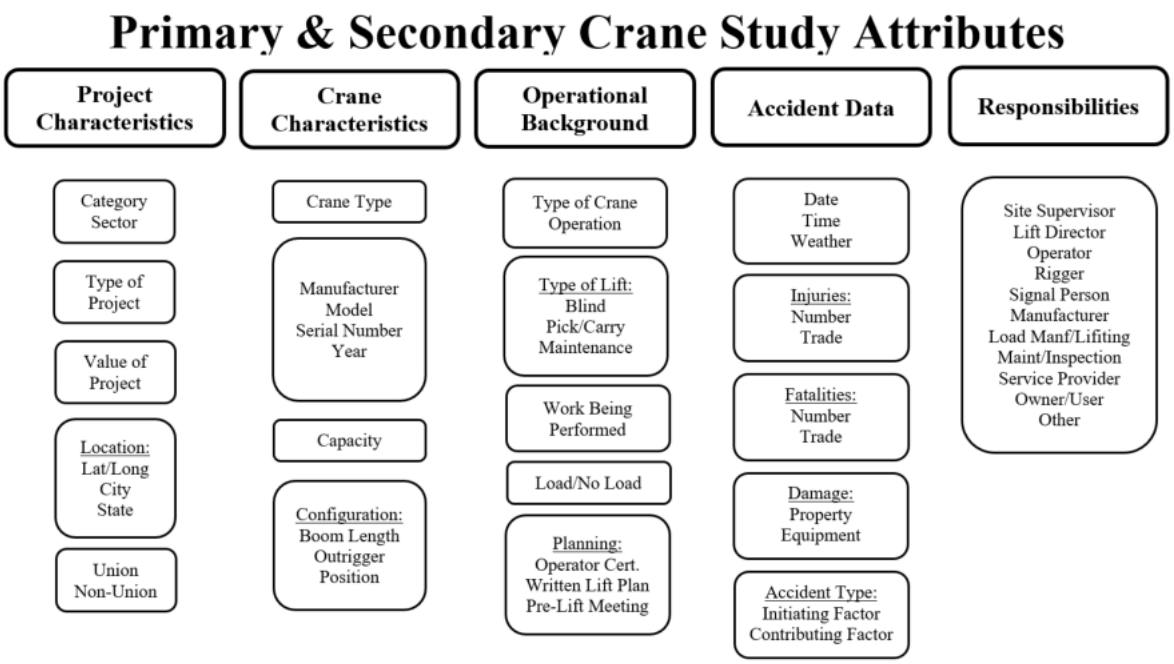

Figure 3: Primary & Secondary Crane Study Attributes

Primary and secondary attributes concerning Research Questions 1 and 2, provided general and specific information for the overall crane industry and for each independent industry sector. Each accident analysis includes identifications of the responsible parties, based on the ASME B30.5-2007 standard, *Mobile and Locomotive Cranes*. This standard identifies and lists specific duties of all parties involved in a crane lift. Even though the ASME B30.5 standard was published in 2007, these duties have been applied, to at least some extent to accident cause evaluations, as far back as early 1980s. The standard duties, as applied to the lifts, provide useful information describing the progression, changes, and trends within the crane industry as well as the effects of personnel training and certifications in reducing crane accidents.

3.4 Crane Use Categories

The fact that cranes are used in many different industries made obvious the need to include crane use category (sector) as part of the study. Addressing crane accidents based on industry use was important. Initially, the study identified four basic categories: Commercial Construction, Residential Construction, Highway Road and Bridge, and Industrial and Manufacturing. As data collection continued, and at the suggestion of SMEs, the categories were expanded to 10 categories, which included Arborist/Logging, Agricultural Industry, Commercial Construction, Highway Road & Bridge, Industrial/Manufacturing, Marine Industry, Mining Industry, Oilfield- Land Base, Oilfield- Offshore, and Residential Construction.

During the analysis process, it became clear that Manufacturing Industry issues were distinctly different from the Industrial Industry issues. The Industrial Industry was defined as an industry which constructed structures not intended for habitation, waste water treatment plants; power plants; chemical plants; and refineries. Ultimately, the researcher combined Industrial and Refining into one category, established Manufacturing as a single category, and combined Agricultural with a similar industry, Arborist/Logging. The final category list comprised the following: Arborist/Logging/Agriculture, Commercial Construction, Highway Road & Bridge, Industrial/Refinery, Marine Industry, Mining Industry, Manufacturing Industry, Oilfield- Land Base, Oilfield- Offshore, and Residential Construction.

The ability to separate the database in accordance with usage and as related to industry categories, allowed specific data exploration related to individual industries. It also provided overall crane accident analysis information. The categories included date, location, crane type, conditions affecting the accident, causation and consequences of the accident, and responsible parties involved in the accident.

Cataloging was based on forensic engineering reports published by highly qualified, licensed engineers, input from industry experts, photographs, research of consensus industry safety standards, and other available documents. Once cataloged into the database, accident information was analyzed statistically identifying potential risk patterns and trends. Results indicating crane accident patterns were explored to identify areas in which improved safety standardization and increased training/focus was needed. Crane lift accident trends can substantiate or disprove the training benefits and effectiveness of certifying entities involved in crane processes. The results of this study demonstrate the importance of careful lift planning and provide information by which to improve crane designs, develop and streamline industry safety standards, and enhance lift coordination. Lift coordination enhancements derive from examining roles and responsibilities, thereby mitigating crane accident risks.

Issues peculiar to each industry were compared to overall study results to identify problematic issues unique to each particular sector. Since each industry employs different types of workers, there are differing procedural and training requirements associated with crane operations. Furthermore, site conditions and hazards vary dramatically between industries. Finally, industry standards and guidelines differ and are often different from those explained in the ASME B30.5 standards. For example, ASME B30.5 specifically forbids operators from lifting personnel by the hook; however, ANSI Z133.1-2006, the

Arboricultural Operation Safety Requirements standard, provides guidance for lifting personnel into trees while personnel are attached to the crane hook by a harness. The Arboricultural Industry has found that it is far safer to lift individuals into a tree using a crane, as opposed to individuals to climb the tree. The Oilfield Industry also has an independent standard developed by the American Petroleum Institute (API). Applications of national standards cross all category boundaries unless addressed specifically by a particular industry such as the Arborists or the Oilfield Industry.

3.5 VALIDATION OF INPUT DATA

To ensure consistent input quality control, specific informational items were identified which must be available and reviewed in order to qualify for inclusion in the study. In 2012, Ray King, a forensic engineer from the Houston office of Haag Engineering Company, completed graduate studies at the Massachusetts Institute of Technology (MIT). During King's studies, he published his thesis, a summary of 75 crane related accidents using information from the researcher's study/data. King's preliminary study aided in establishing information requirements for incident inclusion. King employed a portion of the researcher's Microsoft Excel input sheets imported into Microsoft Access. The King study provided statistical values/tables for the various incident data parameters but did not include statistical comparisons. Further, the King (2012) study incorporated only five categories: Commercial Construction, Highway Road & Bridge, Industrial, Residential, and Marine. As determined by King (2012), it is crucial that information included in any data set be complete and be inputted consistently. All data, including that used by King (2012), was analyzed and inputted by this researcher to ensure consistent evaluation techniques. The MIT thesis represented a credible model for confirming consistent input quality while demonstrating the need to perform more extensive examination of all 701 crane accidents.

Several accidents actually predated initiation of this study but assignments to analyze them were not received until at least 1987. Initial procedures involved in developing the detailed and comprehensive database for this study analysis included elimination of crane accidents for which too much required information was missing or indeterminate. To ensure credibility of the data analyzed, duplicate cases were removed. For example, several files included original forensic analyses and accident investigation reports in addition to OSHA citation assessments. The researcher also identified some duplications in the original dataset. After identification and further analysis of cases, the researcher determined that cranes were not involved and eliminated those cases from the database. For example, one case involved a claim that a crane traveling across a drill site caused the subgrade to liquefy. Actually, fracking by steam injection, was the sole cause of the soil liquefaction at the site. Reported crane accidents which did not involve the direct participation of a crane were not included.

Procedures developed from the preliminary study required that at least three sources of information from a base list be satisfied in order that the information qualify as a complete evaluation. Haag Engineering Co. could not be the sole source of information. Outside sources had to provide a third-party evaluation and perspective that might not have been addressed or might have been viewed differently by the researcher. Table 5, (below), provides details regarding sources of information used in the compilation of each study. All sources were evaluated after confirmation of the comprehensiveness of dataset details.

The researcher developed precise procedures to ensure consistent and valid information to be entered into the database. Obtaining information external to the researcher's accident investigation reinforced and supplemented information obtained, and conclusions developed by the researcher.

Table 5: Sources of Study and Utilization

Source	Internal	External	Utilization Rationale
Depositions and witness statements		√	Sworn specific testimony of witnesses or parties to the lift.
Documents concerning lift		√	Lift plan details; dimensional layout to confirm operational radius and location of personnel.
Engineering reports from other sources		√	Reports of engineers from outside sources.
Haag Engineering reports	√		Internally generated reports based on inspection and analysis.
Incident reports provided by others		√	Internal reports of causation and recommendations for new safety procedures.
Incident scene inspection	√		Photographs taken at the scene of the accident to document damage/causation.
OSHA report/File		√	OSHA file or report-statements
Photographs provided by others of the scene immediately following the incident		√	Photographs taken by others, normally prior to our arrival at the site.
Testing/Modeling/Video of incident	√		Methods to demonstrate the accident

3.6 ASME B30.5- 2007 Duties and Responsibilities

One unique aspect of this study is inclusion of duties and responsibilities defined by the ASME B30.5-2007 standard. While there is a hierarchy associated with crane lifts, the official assignment of lift duties and responsibilities finally occurred during 2007, with publication of ASME B30.5. This document specified the roles of operators, Signal Persons, and person directing the lift (i.e., Lift Director). For years, the "failsafe" conclusion regarding accident causation was "operator error." There was no consideration of other external factors that potentially could have altered results of an accident. ASCE Report No. 93 (Sale 1998) concluded that when parties are not provided with proper directions or necessary information regarding their roles and responsibilities, the potential for an accident is greatly increased. The 1989 tower crane collapse in San Francisco, CA confirmed this conclusion.

Research has determined that identification of duties and responsibilities originated with the International Association of Bridge, Structural and Ornamental Iron Workers (1952). The *Rigging Manual for Ironworkers, Manual III*, published in 1952, details crane selection, erection, rigging, load handling, signaling, and general lift practices. This manual outlined, specific duties for those involved in the crane lift (i.e., the Crane Operator, the Foreman/Lift Director, the Rigger/Ironworker, and the Signal Person). Similar, yet more advanced, training requirements are included in the 2009 version of the Ironworkers Quality Construction Practices entitled the *Cranes: Reference Manual*. In early/mid 1970's, Donald E. Dickie, P. Eng., Assistant General Manager of Construction Safety Association of Ontario, organized the duties and responsibilities in more detail in presentations and in his three books, *Crane Handbook*, *Mobile Crane Manual*, and *Rigging Manual.*

The *ASCE's Manuals and Reports on Engineering Practice* (No. 93) was the first U.S. publication that specified requirements regarding the duties and responsibilities of U.S. Crane Operators. ASCE adopted this publication titled *Crane Safety on Construction Sites*, on April 16, 1994. This publication was created following the San Francisco tower crane incident. In response to the collapse, the American Society of Civil Engineers appointed a Task Force to conduct a comprehensive review of crane safety on construction sites. This special publication addressed variations of usage and organization by clearly defining and assigning crane management responsibilities. For the first time in history, a graphic in the document clearly defined the duties of those involved in the lifting operation process (see Figure 4).

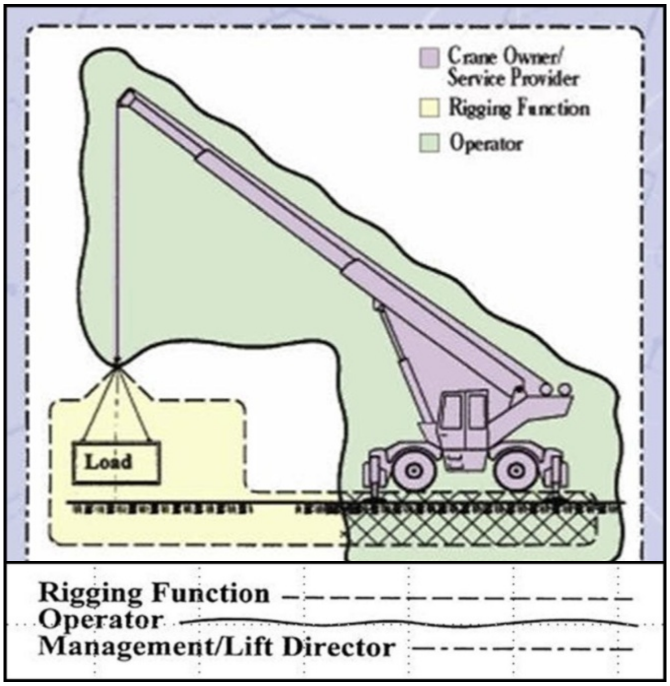

Figure 4: Zones of Responsibility

One of the major problems identified during the San Francisco crane investigation was limited understanding among parties by workers at the site of their individual responsibilities. ASCE 93, a 104-page report, established guidelines and responsibilities for Crane Owners, Project Owners, Architect-Engineers, Service Providers, Crane Operators, Riggers, Lift Directors, Site Supervisors, Signal Personnel, Users, and PC/CMs (Prime Contractor/Construction Managers). Each party was assigned with a detailed description of their responsibilities. Further, the document included a table that addressed every aspect of the lift process from project initiation to the actual lift.

During the early 2000s, the American Society of Mechanical Engineers' B30.5-Mobile and Locomotive Cranes subcommittee began collecting all available information regarding duties and responsibilities for those involved in crane projects. This list also included an operations standard section. Since ASME B30 is an ANSI certified national consensus standard, the committee must maintain a balance between the interests of Crane Owners, manufacturers, labor, government, consultants, trainers, etc., to ensure that no one interest group controls the standard. In 2007, ASME issued the ASME B30.5 standard to become effective one-year later, in 2008. The initial duties list included roles and responsibilities for Operators, Signal Persons, and the person who directs the lift (Lift Director). Ultimately, the person directing the lift became designated as the Lift Director and the ASME B30.20, *Below-the-Hook Lifting Devices*, called out specific duties and responsibilities for Riggers. ASME cited the following rationale for developing the specific duties and responsibilities lists for crane lift personnel:

> Rationale: Since 1982 Section 5-3.1.3 has dealt with the conduct of operators only. The crane operator alone cannot ensure the safety of lifting operations. There are other parties who are an integral part of crane and lifting operations and who must also fulfill their responsibilities if safety is to be achieved. Section 5-3.1.3 has been modified to identify the key parties associated with crane and lifting operations and to delineate the corresponding responsibilities of which they must be aware (ASME B30.5 Ballot TR#: 02-2094, December 14, 2005, p.5).

In the sections below, the duties and responsibilities, as issued by ASME B30.5-2007, are described.

3.6.1 B30.5 Responsibilities

While the organizational structure of various industries and project teams may differ, the following roles are described for the purpose of delineating responsibilities. All responsibilities listed below shall be assigned in the organization’s worksite. It is important to note that a single individual may perform one or more of these roles.

Table 6: Roles and Responsibilities

Roles	Responsibilities
Crane Operator	Directly controls the crane's functions.
Crane Owner	Possesses custodial control of the crane by virtue of lease or ownership.
Crane User	Arranges the crane's presence on a worksite and controls the crane's use on the site.
Lift Director	Directly oversees the work being performed by a crane and the associated rigging crew.
Site Supervision	Exercises supervisory control over the worksite on which a crane is being used and over the work which is being performed on that site.
Rigger	Attaches the load to be lifted to the crane hook using slings, shackles, spreader beams, safety hoist rings, etc., and other gear as appropriate

3.6.1.1 Responsibilities of the Crane Operator

The Crane Operator has many responsibilities, as noted below. Yet, there are some responsibilities that the Crane Operator does not have. For example, the Crane Operator shall not be responsible for hazards or conditions that are not under his/her direct control and that adversely affect the lift operations. Whenever the operator has doubt as to the safety of crane operations, the operator shall stop the crane's functions in a controlled manner. Lift operations shall resume only after safety concerns have been addressed or the continuation of crane operations is directed by the Lift Director. According to B30.5, the Crane Operator's responsibilities include:

a) Understanding and applying the information contained in the crane manufacturer's operating manual.

b) Understanding the crane's functions and limitations, as well as its particular operating characteristics.

c) Knowing what types of site conditions could adversely affect the operation of the crane and consulting with the Lift Director concerning the possible presence of these conditions.

d) Ensuring that all controls are in the off or neutral position and that all personnel are in the clear before energizing the crane or starting the engine;

e) Using the crane's load/capacity chart(s) and diagrams and applying all notes and warnings related to the charts, to confirm the correct crane configuration~~s~~ to suit the load, site, and lift conditions.

f) Knowing and following the procedures specified by the manufacturer or approved by a qualified person, for assembly, disassembly, setting up, and reeving the crane.

g) Observing each outrigger during extension, setting and retraction or using a Signal Person to observe each outrigger during extension, setting or retraction.

h) Performing a daily inspection as specified in 5-2.1.2(a)(c)(d) (h) and 5-2.4.2(a)(1).

i) Testing the crane function controls that will be used and operating the crane only if those function controls respond properly.

j) Promptly reporting the need for any adjustments or repairs to a designated person.

k) Following applicable Lock Out/Tag Out procedures.

l) Considering all factors known that might affect the crane capacity and informing the Lift Director of the need to make appropriate adjustments.

m) Reviewing the requirements for the crane with the Lift Director before operations.

n) Ensuring that the load and rigging weight(s) have been provided.

o) Calculating or determining, the net capacity for all configurations which will be used and verifying, using the load/capacity chart(s), that the crane has sufficient net capacity for the proposed lift.

p) Understanding basic load rigging procedures. For responsibility of rigging the load and ensuring that the load is rigged properly see Sections 5-3.1.3.2.2(h) and (i).

q) Knowing the standard and special signals as specified in Section 5-3.3 and responding to such signals from the person who is directing the lift or an appointed Signal Person. When a Signal Person is not required as part of the lift operation, the Operator is then responsible for the movement of the crane. However, the Operator shall obey a stop signal at all times, no matter who gives it.

r) Operating the crane's functions, under normal operating conditions, in a smooth and controlled manner.

s) Not operating the crane when physically or mentally unfit.

t) Not engaging in any practice that will divert his attention while actually operating the crane controls.

u) Refusing to operate the crane when any portion of the load or crane would enter the "Prohibited Zone" of energized power lines except as defined in 5-3.4.5.4.

v) Knowing how to travel the crane.

w) If power fails during operations-

a. setting all brakes and locking devices;

b. moving all clutches or other power controls to the off or neutral position;

c. landing any load suspended below the hook under brake control if practical;

d. before leaving the crane unattended;

e. landing any load suspended below the hook, unless the requirements of 5-3.2.1.4(d) are met;

f. disengaging the master clutch;

g. setting travel, swing, boom brakes, and other locking devices;

h. putting controls in the off or neutral position;

i. stopping the engine: An exception to this may exist when crane operation is frequently interrupted during a shift and the operator must leave the crane. Under these circumstances, the engine may remain running and paras, (1) through (4) above shall apply. The operator shall be situated where any entry to the crane can be observed.

x) Considering the recommendations of the manufacturer for securing the crane, when a local weather storm warning exists.

3.6.1.2 Responsibilities of the Crane Owner and the Crane User

In some situations, the Crane Owner and the Crane User may be the same entity and is therefore accountable for all of the responsibilities listed below. In other cases, the Crane User may lease or rent a crane from the Crane Owner without supervisory, operational, maintenance, support personnel, or services from the Crane Owner. In these situations, the following shall apply.

The Crane Owner's Responsibilities

a) Providing a crane that meets the requirements of Chapters 5-1 and 5-2 of this volume, as well as specific job requirements defined by the user.

b) Providing a crane and all necessary components, specified by the manufacturer, that meets the Crane User's requested configuration and capacity.

c) Providing additional technical information pertaining to the crane, necessary for crane operation, when requested by the Crane User.

d) Providing all applicable load/capacity chart(s) and diagrams.

e) Providing field assembly, disassembly, operation, and maintenance information, warning decals and placards installed as prescribed by the crane manufacturer.

f) Establishing an inspection, testing, and maintenance program in accordance with Chapter 5-2 and inform the Crane User of the requirements of this program.

g) Using personnel that meet the requirements for a designated person as defined in para. 5-0.2.2 for the purposes of maintenance, repair, transport, assembly and disassembly.

h) Using personnel that meet the requirements for a qualified or designated person as defined in para. 5-0.2.2, for inspections as required in Section 5-2.1.

The Crane User's Responsibilities

a) Complying with the requirements of this volume, manufacturer's requirements and those regulations applicable at the worksite.

b) Ensuring that the crane is in proper operating condition prior to initial use at the worksite by:

   a) verifying that the Crane Owner has provided documentation that the crane meets the requirements of Section 5-2.1.5 of this volume.

   b) verifying that a "Frequent Inspection" has been performed as defined in 5-2.1.2.

c) Verifying that the crane has the necessary lifting capacity to perform the proposed lifting operations in the planned configuration.

d) Using supervisors for crane activities that meet the requirements for a qualified person as defined in para. 5-0.2.2.

e) Using Crane Operators that meet the requirements of 5-3.1.1 and 5-3.1.2 (f). Additional qualifications may be necessary to perform the tasks that will be required with the crane which they are assigned to operate.

f) Ensuring the assigned operator(s) has been notified of adjustments or repairs that have not yet been completed, prior to commencing crane operations.

g) Using personnel that meet the requirements for a qualified or designated person as defined in para. 5-0.2.2, for inspections as required in Section 5-2.1.

h) Using personnel that meet the requirements for a designated person as defined in para. 5-0.2.2 for the purposes of maintenance, repair, transport, assembly and disassembly.

i) Ensuring that all personnel involved in maintenance, repair, transport, assembly, disassembly and inspection are aware of their responsibilities, assigned duties, and associated hazards.

j) Ensuring that the inspection, testing, and maintenance programs specified by the Crane Owner are followed.

3.6.1.3 Responsibilities of the Site Supervisor and the Lift Director

In some situations, the Site Supervisor and the Lift Director may be the same person.

The Site Supervisor's Responsibilities

a) Ensuring that the crane-meets the requirements of Chapter 5-2 prior to initial site usage.
b) Ensuring that a qualified person is designated as the Lift Director.
c) Determining if additional regulations are applicable to crane operations.
d) Ensuring that Crane Operators meet the requirements of para. 5-3.1.2.
e) Ensuring that the area for the crane is adequately prepared. The preparation includes but is not limited to the following:
    a) access roads for the crane and associated equipment;
    b) sufficient room to assemble and disassemble the crane;
    c) an operating area that is suitable for the crane with respect to levelness, surface conditions, support capability, proximity to power lines, excavations, slopes, underground utilities, subsurface construction and obstructions to crane operation.
    d) traffic control as necessary to restrict unauthorized access to the crane's working area;
f) Ensuring that work involving the assembly and disassembly of a crane is supervised by a qualified person.

g) Allowing crane operation near electric power lines only when the requirements of para. 5-3.4.5. have been met.

h) Ensuring that conditions which may adversely affect crane operations are addressed. Such conditions include but are not limited to:

   a) Poor soil conditions

   b) Wind velocity or gusting winds

   c) Heavy rain

   d) Fog

   e) Extreme cold

   f) Artificial lighting

i) Ensuring that work performed by the rigging crew is supervised by a qualified person.

j) Ensuring that crane operations are coordinated with other job site activities that will be affected by or will affect lift operations;

k) Permitting special lifting operations only when equipment and procedures required by this volume, the crane manufacturer, or a qualified person are employed. Such operations include but are not limited to:

   a) multiple crane lifts;

   b) lifting personnel;

   c) pick and carry operations.

l) Ensuring that crane maintenance is performed by a designated person.

Responsibilities of the Lift Director

In some situations, the Crane Owner and the Crane User may be the same entity and is therefore accountable for all of the responsibilities listed below. In other cases, the Crane User may lease or rent a crane from the Crane Owner without supervisory, operational, maintenance, support personnel, or services from the Crane Owner. In these situations, the following shall apply.

The Lift Director's Responsibilities

a) Being present at the jobsite during lifting operations.
b) Ensuring that the preparation of the area needed to support crane operations has been completed before crane operations commence.
c) Ensuring necessary traffic controls are in place to restrict unauthorized access to the crane's work area.
d) Ensuring that personnel involved in crane operations understand their responsibilities, assigned duties and the associated hazards.
e) Appointing the Signal Person(s) and conveying that information to the crane operator.
f) Ensuring that Signal Person(s) appointed meet the requirements of Section 5-3.3.
g) Informing the crane operator of the weight of loads to be lifted, as well as the lifting, moving and placing locations for these loads and obtain the operator's verification that this weight does not exceed the crane's rated capacity.
h) Ensuring that a crane's load rigging is performed by designated personnel as defined in para. 5-0.2.2.

i) Ensuring that the load is properly rigged and balanced before it is lifted more than a few inches.

j) Ensuring precautions are implemented when hazards associated with special lifting operations are present. Such operations include but are not limited to:

   a) multiple crane lifts;

   b) lifting personnel;

   c) pick and carry operations;

   d) mobile cranes operating on barges.

k) Allowing crane operation near electric power lines only when the requirements of para. 5-3.4.5 and any additional requirements determined by the Site Supervisor have been met.

l) Stopping crane operations if alerted to an unsafe condition affecting those operations.

m) Addressing safety concerns raised by the operator or other personnel and being responsible if he decides to overrule those concerns and directs crane operations to continue. In all cases, the manufacturer's criteria for safe operation and the requirements of this volume shall be adhered to.

n) Ensuring that the applicable requirements of ASME B30.23 are met when lifting personnel.

3.6.1.4 Responsibilities of the Rigger

In some situations, the Crane Operator and the Rigger may be the same entity and is therefore accountable for all of the responsibilities listed below.

The Rigger's Responsibilities (ASME B22-3.1.3.3.2)

The Rigger's responsibilities shall include the following:

a) Determine or know the weight and estimate the center of gravity of the load to be lifted.

b) Select and inspect rigging gear such as slings, shackles, safety hoist rings, lifting beams, etc., before use.

c) Ensure that the working load limit of the rigging gear selected is sufficient for the load to be lifted.

d) Properly attach and secure the load to the crane hook using the appropriately selected rigging gear.

e) Ensure sufficient protection for load, slings, and other rigging equipment that could be cut or damaged during load handling activities

f) Ensure that the load is properly rigged and balanced before it is lifted more than a few inches (several centimeters).

g) Know and provide correct signals to the crane operator.

The cranes-Derrick Advisory Committee (C-DAC) was assembled early 2000s to update the prior OSHA 1926.550 standard. During November 2010, OSHA 1926.1400 was issued following public review during the summer of 2010. OSHA 1926.1400 includes reference to the B30 standard requirements.

3.7 CRANE LIFT DEVELOPMENT

The ASME rationale for prescribing duties and responsibilities, "The crane operator alone cannot ensure the safety of lifting operations. There are other parties who are an integral part of crane and lifting operations and who must also fulfill their responsibilities if safety is to be achieved" (ASME B30.5 Ballot TR#: 02-2094, December 14, 2005, p.5). To understand all duties of responsible parties, the researcher has developed a theoretical lift plan to identify parties involved with preparing a lift plan. Utilizing literature searches, past experience with planning lifts, and the ASME responsibilities list, the researcher identified all parties who provide input or have specific duties in lift plan development.

The ASME's P30.1-2014 standard, *Planning for Load Handling Activities*, continues to be the most current guide for lift planning. This ASME P30.1 standard has established that the "lift planner" is essential on every construction project and with overall lift process. An individual designation of lift planner was not called out in the original plan assembly since multiple participants of the lift project could perform that function. There were multiple occurrences where secondarily responsible personnel were required to check or ensure that particular tasks were complete and correct.

With the exception of the crane and load manufacturers, every primary party task was assigned, and a secondary, redundant party task was assigned to ensure lift safety and proper safety checks and balances. The initial purpose of the examination was to identify all parties involved in planning lifts and to demonstrate what input each provided. Table 7, below, overviews the responsible parties and provides details regarding designated primary (P) and secondary (s) responsibilities of the listed parties.

Table 7: Crane Lift Development- Primary and Secondary Responsibilities

Crane Lift Development

Primary Responsibility = P
Secondary Responsibility = s

	Site Supervisor	Lift Director	Operator	Rigger	Crane Manuf.	Load Manuf.	Signal Person	Service Provider	Owner/User	Maint/Insp.
Crane meets design requirements of ASME					P			s	s	
Crane is Inspected and Certified in accordance with ASME and OSHA	s	s						P	P	P
Identify current hazards that exists at the site	P									
a. Power line	P	s	s	s						
b. Trenches/excavations	P									
c. Other cranes	P									
d. Monitor environmental conditions	P	s	s	s						
Provide site ingress and egress of crane	P									
a. Prepared craneway	P									
b. Sufficient subgrade to support crane	P	s	s	s						
c. Underground hazards	P									
d. Approved location of crane for lift	P	s	s							
Development of Lift Plan		P								
a. Determine location of crane.	P	s	s							
b. Determine the weight of the load		P	s							
c. Determine the height and radius the load must be llifted		P								
d. Identify potential interferences or obstructions are involved?		P								
g. Selection of the crane and configuration		P								
h. Does the radius and weight fall within the load chart?		s	P							
i. Is landing area sufficient to support load?	P	s								
j. What environmental conditions may affect lift?	s	P	s	s	s					
k. Assign a qualified rigging crew		P		P						
How is the load to be rigged?		s		P						
a. Lifting lugs						P				
b. Is C.G. of load known if no lifting lugs				s		P				
c. Is load stable when lifted a short distance			s	P						
d. Single or multiple pieces to be lifted		s		P						
What rigging is required?		s		P						
a. Are there sharp edges-softeners required		s		P						
b. Are tag lines required		s		P						
c. Ensure stability of load prior to final lift				P						
Assign a designated signal person		P								
Crane Signals			P				P			
a. Understand signals-qualified			s				P			
b. What directions are necessary to lift, swing/boom and place?			s				P			
c. Maintain visual with operator and landing area							P			
d. Avoid all potential obstructions			s				P			
e. Receiving signal person for final placement							P			
Load movement			P							
a. Operator is Certified-Qualified to operate the crane		s	P					P	P	
a. Ensure load within charts		s	P							
b. Move load in a controlled manner			P							
d. Land load			s	s			P			
e. Determine environmental effects on crane		s	P							
f. Basic knowledge of rigging		s	s	P						

The purpose of this lift development guideline is to provide list of the entities required to organize and produce a lift plan. A complete understanding of all responsible parties has been lacking in prior studies. The theoretical lift plan development clearly depicts those parties that have input into the plan which go beyond personnel that conduct the lift. The number of primary and secondary responsibilities have been summed, and a percent accountability factor of each party, established. Initially, both primary and secondary tasks were assigned equal values of one; however, to better reflect the level of responsibility, primary was assigned a value of two.

Table 8: Primary/Secondary Responsibilities (Weighted)

Crane Lift Development	Site Supervisor	Lift Director	Operator	Rigger	Crane Manuf.	Load Manuf.	Signal Person	Service Provider	Owner/User	Maint. Inspection	TOTALS
Primary Responsibility	12	8	7	9	1	2	7	2	2	1	51
Secondary Responsibility	2	17	13	6	1	-	-	1	1	-	41
	14	25	20	15	2	2	7	3	3	1	92
	15.2%	27.2%	21.7%	16.3%	2.2%	2.2%	7.6%	3.3%	3.3%	1.1%	100.0%
WEIGHTED: Px2; sx1											
Primary Responsibility	24	16	14	18	2	4	14	4	4	2	102
Secondary Responsibility	2	17	13	6	1	-	-	1	1	-	41
	26	33	27	24	3	4	14	5	5	2	143
	18.2%	23.1%	18.9%	16.8%	2.1%	2.8%	9.8%	3.5%	3.5%	1.4%	100.0%

The four most responsible parties remain the same for both regular and weighted averages: Lift Director (23.1%), Operator (18.9%), Site Supervisor (18.2%) and Rigger (16.8%). The Site Supervisor and Rigger do exchange positions in the weighted analysis. Examination of a theoretical lift plan clearly demonstrates that multiple parties must be involved in the lift development process and critical to the ultimate outcome of the crane lift. Each individual responsible for performing specific tasks has a direct bearing in assuring safe success of a lift. The size of the project and weight of the load being lifting will result in some personnel being assign multiple roles. ASME B30 references the possibility that the Site Supervisor and Lift Director may be, in some instances, the same person. Therefore, under those conditions, the Site Supervisor/Lift Director is responsible for 41.3% of the critical input items for a lift. Incorrect information and failure to perform required tasks, both human intervention factors, are primary contributing factors for crane accidents.

The National Commission for the Certification of Crane Operators (NCCCO) developed a program for the Lift Director, which was implemented in late 2016 with the first Lift Director certification issued in first quarter of 2017. The Lift Director certification requires testing in the following areas of competency:

- Site control and evaluation
- Roles, responsibilities of parties, and required qualifications of lift personnel
- Lifting operations
- Lift Plans
- Rigging
- Signaling
- Read and understand load charts
- Hydraulic and Lattice Boom

In accordance with the NCCCO requirements, the Lift Director must be proficient in crane operations and understand the requirements of a Crane Operator (i.e., hazard, load charts, operation, etc.), Rigger (i.e., application of the rigging and proper selection), signaling (i.e., proper signals and dynamics of cranes), site (i.e., site conditions, preparation and existing hazards of the site), roles (i.e., understand and explain the responsibilities of the crew members to perform a lift), lifting operations (i.e., swing path, obstructions, load stability, selection of Riggers, Signal Person, and placement of field personnel), and the lift plans (i.e., develop lift plans and direct the operation). The Lift Director's role is paramount to safe lifting procedures and requires proper direction and control of the operation and field personnel. The theoretical lift plan provides an understanding of the roles of all parties of a lift and demonstrates that the operator is responsible for movement and control of the load from the lifting point to the final placement in accordance with ASME. More specifically, ASME requires that the Crane Operators not divert his/her attention from this role, thus requiring all parties perform their assigned tasks properly and safely. The Lift Director's role is to ensure collaboration between all parties by maintaining continuous communications of the lift crew which is critical immediately prior to the lifting process.

3.8 ASME P30.1-5-3 Pre-Lift Meeting

ASME P30.1 provided a Pre-Lift Meeting list of items that should be address before lifting. The Lift Director *should* hold a pre-lift meeting to discuss the plan and the roles of the personnel involved in the lift. Pre-Lift Meeting list requirements include the following components-

a) At a minimum, the following elements should be reviewed with all load handling activity personnel:
    a) Overview of the load handling activity;
    b) LHE (Load Handling Equipment), rigging, and other equipment involved in the load handling activity;
    c) The sequence of events and step-by-step procedures for the entire load handling activity;
    d) Safety measures, as required (e.g., Job Safety Analysis action items);

e) Load handling activity personnel assignments, addressing:

   i. individual responsibilities (e.g., location, task, time)
   ii. work location hazards (e.g., pinch points)
   iii. communication methods
   iv. personal protective equipment requirements
   v. qualification(s) of assigned personnel (certification)

f) Any contingency measures as determined in para. 5-2.9.

g) Any emergency action plan as determined in para. 5-2.10.

b) Concerns raised during this meeting shall be addressed prior to proceeding with the load handling activity.

c) At the completion of the pre-lift meeting, the Lift Director should confirm that the attendees understand the plan and their roles and responsibilities during the load handling activity.

d) For repetitive lifts, the Lift Director should decide the frequency of pre-lift meetings. Pre-lift meetings may not be required prior to each repetition of the load handling activity.

The P30.1 pre-lift meeting guidelines are recommendations ("should") and are appropriate for all types of lifts (i.e., Critical, General, and Production). This format is recommended for all lifts, since it bridges the gap between what the crew believes the lift entails and what the lift actually entails. Based on the evaluation of over 701 crane accidents, the lack of a pre-lift meeting would have addressed initiating or contributing factors of the incident, had such a meeting been performed. Study revealed that a pre-lift meeting did not occurred in over 62% (n = 440) of the 701 accidents analyzed.

3.9 CHAPTER CONCLUSION

This chapter has outlined the procedures employed, validated data, and discussed aspects of crane lift development. Understanding the detailed elements of crane lifts is paramount in effectively analyzing the causes of crane accidents. An understanding of accident causation can ensure that safety procedures are upheld and that parties are carrying out their assigned duties and responsibilities. The Crane Operator is one of many parties that provides input and conducts their responsibilities in a manner that has found to be effective and safe. Collaboration and communication among all parties are the overriding parameters for the successful and safe completion of a lift. Workers must be aware of their responsibilities before a lift begins. Furthermore, certified training experts must educate all parties involved in the lift regarding their duties. When these parties carry out all of their assigned duties and responsibilities, effectiveness of the overall team, that is all crew members and all supervisors, is assured.

Chapter 4- Findings from the Data Analyses and Trends

This chapter presents the makeup and construction of the study database, completeness of the input data evaluation, discussion of the estimated population, rationale of data analysis and description of statistical analysis applied. An analysis was performed to address an estimated number of crane accident that occurred during the term of the study. Fatality data obtained from OSHA between 1992 and 2016 was compared to the number of fatalities during that same period. A factor between the fatal and non-fatal accidents was applied to the annual OSHA death rate for a 35-year period to estimate the total population of crane accidents.

4.1 Database Construction

The original database was in Microsoft Excel and contained 108 variables involved in 701 crane accidents from 1983 to 2017 crane accidents. The criterion inclusion as completed analysis of each accident was a three-fold process. First, by expert consensus, it was agreed that a minimum number of sources for all cases that "qualified" to be input into the databases needed to be operationalized. At least one outside source of information not prepared by the research was required to be included in the study. Further, an actual video of the accident, of which there were many, could supplement for an outside source. At least three of the following were the primary sources of information relied upon for each evaluation:

- Haag Engineering reports
- Engineering reports from other sources
- Documents concerning the lift
- Incident scene inspections

- Photographs provided by others at the scene, taken immediately following the incident
- OSHA report/file
- Incident report by others
- Depositions and witness statements
- Testing, modeling, or video of the incident

The aforementioned components became the criteria for a crane accident to be included in the study database based on meeting specific number and type of sources used. The researcher then separated out those incidents where an injury or death occurred; however, there was no physical damage to the crane or load. For example, the load dropped on a worker, the load pinched a worker (against a wall), the crane struck a worker, the load was being lifted inside a building (blind lift) and struck a worker, etc. These events would demonstrate that even a well-planned lift can result in an injury or death due to worker inattention or lack of supervision.

4.2 Descriptive Statistics

There are two types of statistics that will be used in this data analysis. First, descriptive statistics will be used to take large amounts of data and reduce them into more understandable units. Descriptive statistics used together with simple graphical analysis, essentially based on every quantitative analysis (Sheskin 2011). The variables in the crane accident data set are either nominal or ordinal. Nominal variables have groups that have no ranking such as gender (female and male), while ordinal groups have an inherent ranking or a given ranking like strength (i.e., weak, moderate, strong). The descriptive statistics used to present nominal and ordinal variables are frequency and percent. These are arranged in a table known as a frequency distribution (Sheskin 2011). Descriptive statistics will be used largely in the Observations section.

4.3 Data Cleaning

The data was uploaded from Microsoft Excel to SPSS, version 24.0. The process of data cleaning is about detecting and correcting (or removing) inaccurate records from a table or database and refers to identifying incomplete, incorrect, inaccurate or irrelevant parts of the data and then replacing, modifying, or deleting the affected data (Xu, Ihab, Sanjay, and Jianna 2016).

4.3.1 Coding Errors

The process of changing to SPSS involved creating a list of all variables, variable type, column width, decimal places, variable labels and variable codes in SPSS. It was very important to decide which variables were crucial to the analysis and *must* have values for the responses to be complete. Next, looking for coding errors, such as, in the case of gender will have in most cases the possible codes of 1 = male, 2 = female, 0 = missing, and so, in this case, a code of 22 would be an error, other errors might include missing data values. This was checked and corrected using frequency tests (Xu, Ihab, Sanjay, and Jianna 2016).

4.3.2 Outliers

The issue of statistically significant outliers can adversely impact data, especially if the sample is small. Moreover, outliers can hide or create statistical significance and are important to identify. This can be done by creating a bar graph or boxplot, or similar is one way to quickly identify outliers. Further, check for logical consistency of answers and use cross-tabulating pairs of variables is to find inconsistencies. This was done, and no significant inconsistencies were found (Xu, Ihab, Sanjay, and Jianna 2016).

4.3.3 Missing or Incomplete Data

The guidelines for missing and incomplete data start with deciding how to deal with incorrect or missing values. Suggested methods are removing responses with missing or incorrect values, correct missing or incorrect data if the correct value is known, going back to the data source and filling in the missing data variables, setting values to an average or other statistical value, and coding as missing with a number like -999 (Xu, Ihab, Sanjay, and Jianna 2016).

4.4 Population Sample of Crane Accidents

There are approximately 46,850 mobile cranes in the US and 2,500 tower cranes as of 2016. From 1992 to 2016, OSHA reports there have been 868 total crane fatalities in the U.S. There was a total of 701 crane accident investigations and 175 deaths from 1983 to 2017 included in this dissertation (Figure 5).

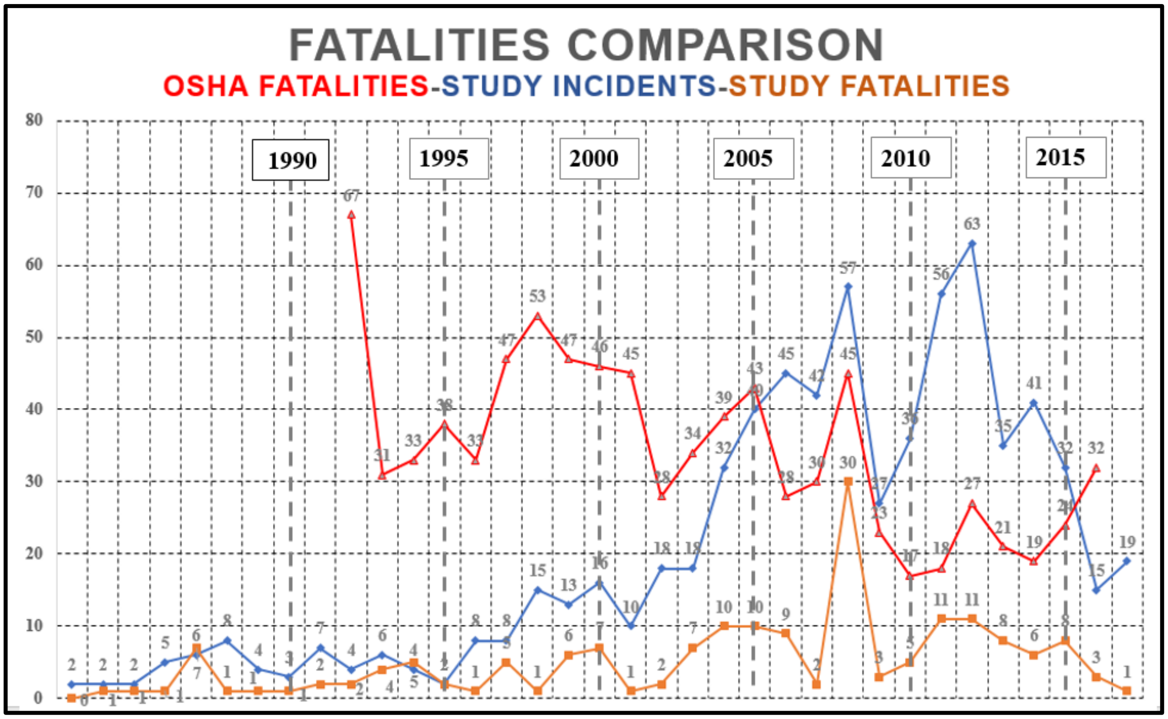

Figure 5: Fatalities Comparison- OSHA Fatalities, Study Incidents, and Study Fatalities (1992-2016)

Data received from OSHA Directorate of Construction indicated that records were not specifically collected on crane-related fatalities until 1992. According to information provided fatalities associated with crane accidents between 1992 and 2016 totaled 868 fatalities. During the same period the study documented 159 fatalities. Average annual fatality rates were 6.36 for the study and 34.72 per OSHA which were approximately 5.46 times more fatalities per year. Of the 701 study accidents, 557 occurred without a fatality while 144 resulted in at least one fatality or 3.8 (557/144) times more non-fatal accidents as fatal, and a factor of 4.8 (701/144) total accidents to fatal. Applying a factor of 4.8 to the annual OSHA fatality rate of 34.72 we arrive at approximately 167 total accidents per year. Over a 35-year period of the study would equate to a total estimated population of accidents of 5,833 during the study period. A sample size of 701 accidents with a population of 5,833 would yield a confidence level of 99% with a 4.55% margin of error. If we apply a 20% factor for unreported non-fatal accidents to the estimated total would yield an estimated population of 7,000 accidents. A sample size of 701 would equate to a 99% confidence level with a 4.6% margin of error.

As seen in Table 9, specifically in the Crane Capacity section, an interesting trend occurs with 15-99 tons being involved in 380 (49.1%) crane accidents followed by 100-199 tons (*n* = 133, 17.2%) and 200-299 tons (*n* = 100, 12.9%) where the lowest numbers of accidents occur with the highest tonnage. Thirty (3.9%) accidents at 300-599 tons and 8 (1.0%) at greater than 600 tons. Next, on First Crane Type, Mobile Hydraulic (*n* = 222, 28.7%) and Track-Lattice (*n* = 124, 16.0%) accounted for 346 (44.7%) of all crane accidents. On the other hand, 22 other First Crane Types account for 54.3% of all crane accidents (Figure 6). For Second Crane Type, the same pattern emerged with Mobile Hydraulic and Track-Lattice being involved in the most accidents and three other types following in low. Further investigation into Mobile Hydraulic and Track-Lattice Cranes is suggested.

Table 9: Crane Characteristics

CHARACTERISTIC	**FREQUENCY**	**PERCENT**
Crane Capacity (tons)		
Less than 2	8	1.0
2 to 14	41	5.3
15 to 99	380	49.1
100 to 199	133	17.2
200 to 299	100	12.9
300 to 599	30	3.9
Greater than 600	8	1.0
First Crane Type		
Boom Truck	49	6.3
Derrick	1	.1
Gantry	7	.9
Jib Crane	1	.1
Knuckle Boom	4	.5
Mega Crane	5	.6
Mobile Hydraulic	222	28.7
Mobile Lattice	60	7.8
Mobile RT	67	8.7
Other	6	.8
Overhead	44	5.7
Shop Built	2	.3
Special- Gin Pole	6	.8
Special- Launching Girder	1	.1
Special- Log Boom	1	.1
Special- Marine	10	1.3
Special- Side Boom	1	.1
Special- Straddle Crane	2	.3
Tower- Hammer Head	40	5.2
Tower- Luffing	9	1.2
Tower- Pedestal	21	2.7
Tower- Self-Erect	8	1.0
Track- Hydraulic	10	1.3
Track- Lattice	124	16.

Table 9. cont.

Second Crane Type		
Mobile Hydraulic	9	1.2
Mobile Lattice	3	.4
Overhead	1	.1
Tower- Pedestal	1	.1
Track- Lattice	7	.9

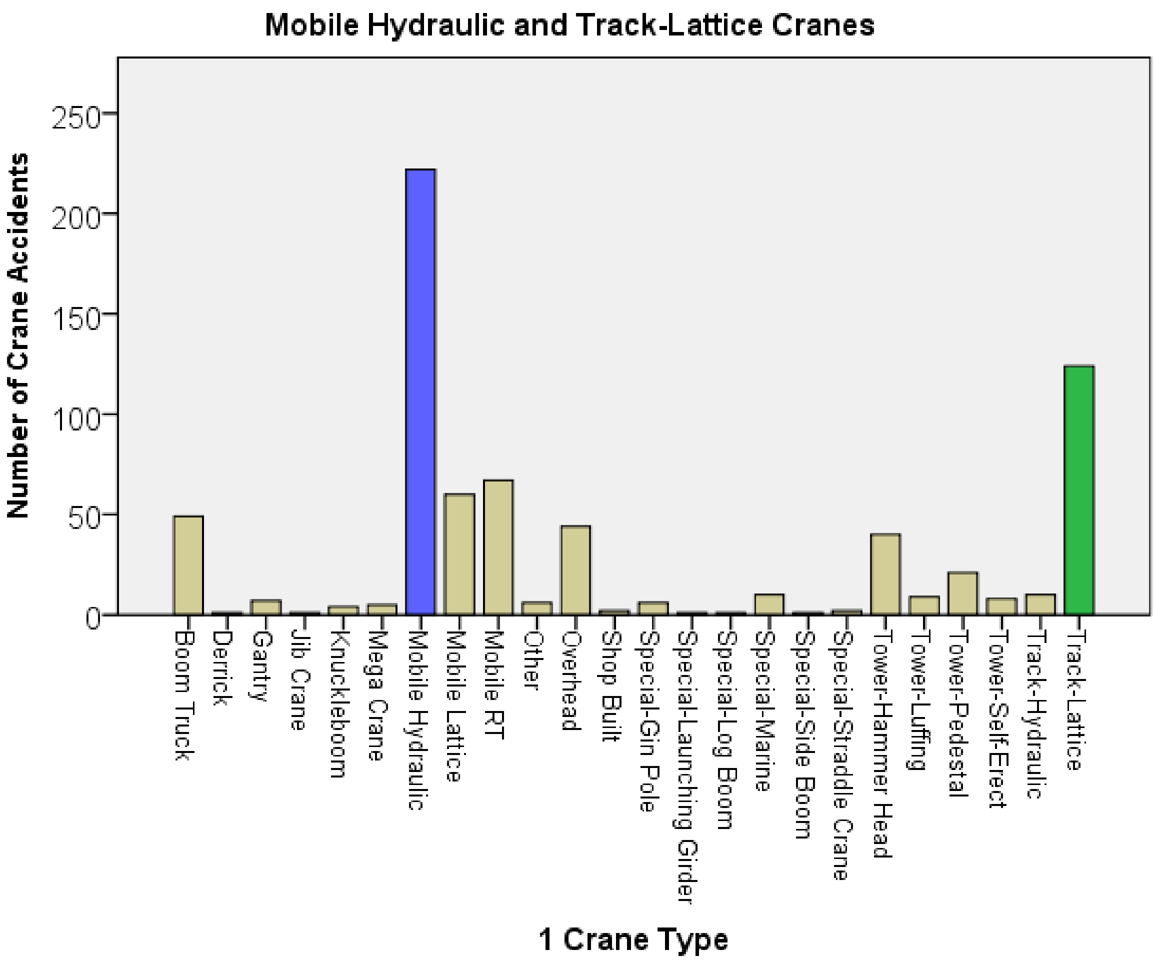

Figure 6. Mobile Hydraulic and Track-Lattice Cranes

4.5 DATA ANALYSIS AND RATIONALE

The second type of statistic is called inferential analysis (Sheskin 2011). The inferential analysis is when one trying to make conclusions beyond the immediate data or generalize to a specific population. The questions become, can the results found, from the sample, be generalized back to the population from which they were drawn (Sheskin 2011).

There are two types of inferential statistics that are known as parametric and non-parametric statistics. Two basic distinctions for parametric versus non-parametric is the level of measurement for the dependent variable (i.e., interval, ratio, nominal, and ordinal). For example, when the dependent variable is nominal or ordinal then one uses non-parametric statistics, or if the data is in interval or ratio level dependent variables, then one uses scales you use parametric statistics (Sheskin 2011). Table 10 examines the differences between parametric and non-parametric statistics.

Table 10: Parametric versus Nonparametric Differences

CONDITION	PARAMETRIC	NONPARAMETRIC
Assumed distribution	Normal	Any distribution
Assumed variance	Homogeneous	Any distribution
Typical data	Ratio or interval	Ordinal or nominal
Data set relationships	Independent	Any
Usual central measure	Mean	Median
Benefits affected by tests	Drawing more conclusions	Simplicity and fewer outliers
Correlation test	Pearson	Spearman
Independent measures	2 groups (independent groups t-tests)	Mann-Whitney test
Independent measures	> 2 groups (one-way, independent measures ANOVA)	Kruskal-Wallis test
Repeated measures	2 conditions (matched pair t-tests)	Wilcoxon test
Repeated measures	> 2 conditions (one-way repeated)	Friedman’s test
Regression	Multiple regression	Multinomial logistic regression

Non-parametric means not of a source population. A non-parametric test is in this strict sense, is essentially a null category, since virtually all statistical tests assume one thing or another about the properties of the source population(s), the non-parametric does not (Sheskin 2011). Non-parametric measures of central tendency are typically the median and mode.

A multinomial logistic regression is non-parametric multiple regression analysis used when the dependent variable is nominal and has more than two levels. Since the SPSS output of the analysis is somewhat different to the logistic regression's output, multinomial regression is sometimes used instead (Menard 2010). Like all linear regressions, the multinomial regression is predictive analysis.

As seen in Table 10, for Research Question 1, a non-parametric multinomial logistic regression was used since the independent variables are all nominal and the dependent variable is a multi-level nominal variable (Menard 2010). Each of the 11 responsibility independent variables was dummy coded (1 = job responsibility and 0 = all other responsibilities). This coding was done in crane accidents involving one person primary, two people primary, three people primary, one-person secondary responsibility and two people secondary responsibility (Menard 2010). Multinomial regression has six assumptions to examine before running the statistic. These assumptions must be met to make sure the appropriate statistic has been chosen.

4.5.1 Assumption 1

The dependent variable should be measured at the nominal level. Examples of nominal variables include variables with 3, 4, and 5 categories or more. In this case, the dependent variable of Accident 1 has twenty nominal categories, Accident 2 has eighteen nominal categories, and Accident 3 has 3 nominal categories (see Table 11). Assumption 1 is met.

4.5.2 Assumption 2

There must be one or more independent variables that are continuous, ordinal, or nominal. There are eleven nominal categories in one group of independent variables, but there are a total forty-one nominal independent variables. Assumption 2 is therefore met.

4.5.3 Assumption 3

There should be the independence of observations (no one participant is in more than one group)**,** and the dependent variable should have mutually exclusive and exhaustive categories. The three dependent variables of Accident 1, Accident 2, and Accident 3 have mutually exclusive and exhaustive categories, so this assumption is met.

4.5.4 Assumption 4

There should be no multicollinearity. Multicollinearity happens when two or more independent variables are highly correlated with each other, usually above .80 (Menard 2010). This high correlation causes a problem in regard to understanding what variable contributes to the explanation of the dependent variable and technical issues in calculating a multinomial logistic regression (Menard 2010). A correlation matrix was run, and there was no multicollinearity**.**

4.5.5 Assumption 5

A linear relationship between any continuous independent variables and the logit transformation of the dependent variable. This could not be done since all the variables are dummy coded and considered nominal.

4.5.6 Assumption 6

There should be no outliers, high leverage values, nor highly influential points**.** There were no statistically significant outliers, high leverage values, nor highly influential points. This assumption was met.

Multinomial logistic regression was used to explain data and the relationship between one nominal dependent variable and one or more continuous-level (interval or ratio scale) independent variables (Menard 2010). This statistic was done to examine Research Question 1 which stated, "Do the duties and responsibilities established by ASME B30.5 appropriately address associated causes of crane accidents by all responsible parties?" Also, to determine if the null hypothesis (below) was to be retained.

$H_0$1. The duties and responsibilities established by ASME B30.5 do not address appropriately associated causes of crane accidents by all responsible parties.

H_A1. The duties and responsibilities established by ASME B30.5 do address appropriately associated causes of crane accidents by all responsible parties.

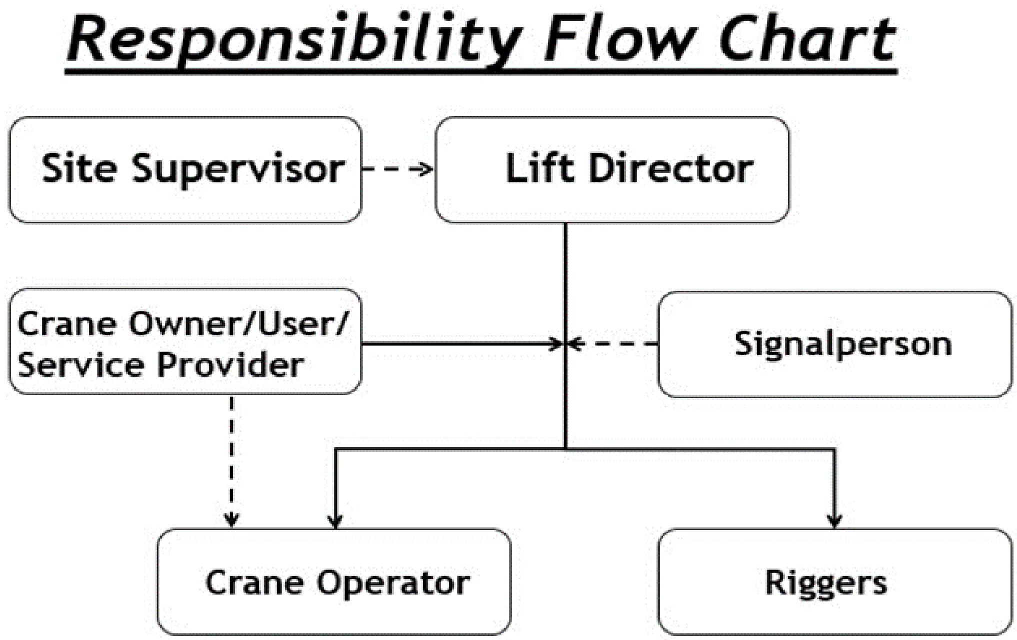

Figure 7: Responsibility Flow Chart

This flowchart, based on ASCE diagram, indicates the path of responsibility in a crane lift operation.

Table 11: Responsible Parties (Independent Variables)

RESPONSIBILITY LEVEL	FREQUENCY	PERCENT
1 Primary Responsibility		
Service Provider	49	6.4
Crane Operator	167	21.6
Lift Director	133	17.2
Manufacturer of Load/Lifting Instructions/Connection Points	14	1.8
Mechanical/Maintenance/Inspection Issue	34	4.4
Other	20	2.6
Owner/User	26	3.4
Rigger	118	15.3
Signal Person	37	4.8
Site Supervisor	103	13.3
2 Primary Responsibility		
Service Provider	4	.5
Crane Operator	31	4.0
Lift Director	36	3.4
Manufacturer of Load/Lifting Instructions/Connection Points	2	.3
Mechanical/Maintenance/Inspection Issue	16	2.1
Other	4	.5
Owner/User	4	.5
Rigger	40	5.2
Signal Person	2	.3
Site Supervisor	9	1.2
3 Primary Responsibility		
Not Assigned	700	99.9
Crane Operator	1	.1

Table 11, cont.

1 Secondary Responsibility		
Value Not Assigned	610	88.2
Crane Operator	23	3.0
Lift Director	24	3.1
Manufacturer of Load/Lifting Instructions/Connection Points	1	.1
Mechanical/Maintenance/Inspection Issue	1	.1
Other	2	.3
Owner/User	1	.1
Rigger	23	3.0
Service Provider	2	.3
Signal Person	5	.6
Site Supervisor	9	1.2
2 Secondary Responsibility		
Not Assigned	699	99.7
Rigger	1	.1
Site Supervisor	1	.1

Table 12: Accident Information- Dependent Variable (n = 701)

QUESTION	FREQUENCY	PERCENT
1 Person Accident Type		
Assembly/Disassembly	22	3.1
Boom/Jib Collapsed	105	15.0
Boom/Jib Dropped	45	6.4
Crane Overturn	129	18.4
Crane Travel/Derailed	12	1.7
Land Load-Stability Failure	44	6.3
Other	12	1.7
Personnel Basket Failure	6	.9
Power Line Contact	26	3.7
Rigging Failure	33	4.7
Signaling	17	2.4
Slewing Assembly Failure	4	.6
Trip/Slip/Fall/Jump From	10	1.4
Two Block	11	1.6
Unstable/Dropped/Lost Load	111	15.8
Worker Contacted by Crane Accident	8	1.1
Worker Contacted by Crane No Accident	30	4.3

Table 12, cont.

QUESTION	FREQUENCY	PERCENT
Worker Contracted by Load Accident	12	1.7
Worker Contacted by Load No Accident	62	8.8
2 Person Accident Type (Missing *n* = 407)		
Boom/Jib Collapsed	2	.7
Boom/Jib Dropped	3	1.0
Crane Overturn	2	.7
Crane Travel/Derailed	1	.3
Land Load-Stability Failure	2	.7
Other	1	.3
Personnel Basket Failure	1	.3
Signaling	3	1.0
Slewing Assembly Failure	1	.3
Trip/Slip/Fall/Jump From	3	1.0
Two Block	2	.7
Unstable/Dropped/Lost Load	14	4.8
Worker Contacted by Crane Accident	94	32.2
Worker Contracted by Load Accident	124	42.5
Worker Contacted by Load No Accident	39	13.4

Table 12, cont.

QUESTION	FREQUENCY	PERCENT
3 Person Accident Type (Missing *n* = 687)		
Worker Contacted by Crane Accident	5	35.7
Worker Contacted by Load Accident	8	57.1
Worker Contacted by Load No Accident	1	7.1

4.6 FINDINGS

Multinomial regression was run using the dependent variable of 1-Person Accident and 1-Person Primary Responsibility, and the result was the Nagelkerke R^2 was equal to .743 and was significant at $X^2(190) = 947.692$, $p < 0.0001$ (Table 13). This means that at 74.3% of one-person accidents were explained by one-person responsibilities. The null hypothesis is rejected, and the duties and responsibilities established by ASME B30.5 do address appropriately associated causes of crane accidents by all responsible parties.

Table 13: Pseudo R- Square

Cox and Snell	.741
McFadden	.226
Nagelkerke	.743

As seen in Table 14, an Odds Risk Ratio of 1.0 means a person had the same chance for exposure to the variable, while under 1.0 means there was a buffer protecting them. An Odd Risk Ratio (ORR) of 2.0 or 3.0 means the person has a 200% or 300% more of a chance being exposed to that variable (Sheskin 2011). As far Odds Risk Ratios go, most of the time the Service Provider, dramatically increased the odds of an accident.

Table 15 shows the accident type and the responsible party from 1-Person Accidents. Starting with an accident on assembly/disassembly, the presence of a Service Provider (SP) causes the Odds Risk Ratio (OR) to rise from 1.0 to 6485.089 times the probability of an accident occurring. For the SP, the range of accidental probability range goes, for an accident to occur goes from 2.978 (Worker Contacted by Load No Accident) to 1,186,610,348,000,000,000.000 (Unstable/Dropped/Lost Load). The rest of the responsibilities increase accidents somewhere between 2.0 to 16.0). The data from 2 and 3-Person Accidents and 1 and two responsible were not statistically significant.

Table 14: Accidents and Responsibilities- An Odds Risk Ratio Analysis

1 ACCIDENT TYPE	ODDS RISK RATIO (ORR)	LOWER BOUND (95% CONFIDENT INTERVAL)	UPPER BOUND (95% CONFIDENT INTERVAL)
Assembly/Disassembly			
[All Other Responsibilities]	578.323	7.497E-8	4,461,314,536,000
[Crane Operator]	6485.089	3.312E-8	1,269,839,579,000,000
Boom/Jib Collapsed			
[Inspection Issue]	15.954	.054	4735.276
[All Other Responsibilities]	15.954	.730	348.762
Boom/Jib Dropped			
[Lift Director]	10.799	.470	248.255
[All Other Responsibilities]	14.214	.004	45091.533
Crane Overturn			
[All Other Responsibilities]	9,520,562.953	.017	5,207,951,685,000,000
[Service Provided]	52,228,930.300	.017	380,886,560,600,000,000
Land Loaded-Stability Failure			
[All Other Responsibilities]	210,333,411.600	.119	370,778,935,300,000,000
[Service Provided]	125,137,440.500	.002	6,414,322,554,000,000,000
Other			
[All Other Responsibilities]	123,528,898.800	.031	493,321,068,700,000,000
[Service Provided]	580,977,834.700	.005	68,163,497,620,000,000,000
Personnel Basket Failure			
[All Other Responsibilities]	8.394	4.324E-10	162,969,286,600
[Service Provided]	39.481	8.439E-11	18,469,530,790,000
Rigging Failure			
[All Other Responsibilities]	22,907,020.520	.001	512,821,702,200,000,000
[Service Provided]	22,907,020.520	002.976E-5	17,631,170,220,000,000,000
Signaling			
[All Other Responsibilities]	74.234	5.330E-9	1,033,852,055,000
[Service Provided]	4.234	1.457E-10	37,831,685,570,000

Table 14, cont.

1 ACCIDENT TYPE	ODDS RISK RATIO (ORR)	LOWER BOUND (95% CONFIDENT INTERVAL)	UPPER BOUND (95% CONFIDENT INTERVAL)
Slewing Assembly Failure			
[All Other Responsibilities]	4.399	.112	172.436
[Lift Director]	4.399	.154	125.420
[Manufacturer of Load/Lifting Instructions /Connection Points]	4.399	4.399	4.399
[Mechanical/Maintenance/ Inspection Issue]	4.399	.014	1402.749
[Other]	5.980	.214	167.198
[Rigger]	4.399	.000	178129.058
[Service Provider]	4.399	.001	14648.648
[Signal Person]	6.164	.209	182.131
Trip/Slip/Fall/Jump From			
[All Other Responsibilities]	3.413	.083	139.866
[Lift Director]	2.593	.095	70.836
[Manufacturer of Load/Lifting Instructions /Connection Points]	3.413	3.413	3.413
[Other]	2.627	.108	63.826
[Rigger]	3.413	8.301E-5	140361.975
[Service Provider]	3.413	.001	11597/681
[Signal Person]	4.783	.154	148.271
Two Block			
[All Other Responsibilities]	17.665	9.090E-10	343,276,669,800
[Service Provider]	83.080	1.774E-10	38,899,509,260,000
Unstable/Dropped/Lost Load			
[All Other Responsibilities]	1,053,274,367,000,000,000	17,014,892,890	65,200,933,080,000,000,000,000,000
[Service Provider]	1,186,610,348,000,000,000	1,447,640,581	972,647,586,700,000,000,000,000,000
Worker Contracted by Crane			
[All Other Responsibilities]	3.413	.083	139.866
[Other]	2.627	.108	63.826
[Crane Operator]	1.123	.039	32.511
[Lift Director]	1.658	.068	40.671
[Signal Person]	2.572	.103	64.203
Worker Contracted by Crane			
[All Other Responsibilities]	13.101	3.933E	4,363,823,718
[Service Provider]	2.978	4.052E-10	2,887,209,320

Large odds ratios are far more inaccurate than relative risk ratios, as it is always further away from 1.0 then relative risk (Andrade 2015). So, the suggestion is to use relative risk when odds ratios are very large (Andrade 2015), such as Assembly/Disassembly where the ORR fell from 6485.089 to the RR of 73.0 (Tables 14 and 15). The 1-Person Accident types were the largest in Table 14 and were converted to RR and one can clearly see the drop-in estimation. Relative risk ratios should be used in Table 15 since they are more accurate. In Table 15, the highest risk situation was Crane Overturn involving the fault or cause of the Service Provider at 335.0 times greater than other accidents. The lowest risk situation was at 13.0 times greater with Personnel Basket Failure and the involvement of a Service Provider.

Table 15: Accidents and Responsibilities- A Relative Risk Ratio Analysis

1-PERSON ACCIDENT TYPE	**RELATIVE RISK RATIOS** (RRR)	**LOWER BOUND** (95% CONFIDENT INTERVAL)	**UPPER BOUND** (95% CONFIDENT INTERVAL)
Assembly/Disassembly [All Other Responsibilities] [Crane Operator]	73.0	4.4891	1187.1102
Crane Overturn [All Other Responsibilities] [Service Provider]	335.0	20.9075	5367.6803
Land Loaded-Stability Failure [All Other Responsibilities] [Service Provider]	89.0	5.4916	1442.3943
Other [All Other Responsibilities] [Service Provider]	25.0	1.430	421.4459
Personal Basket Failure [All Other Responsibilities] [Service Provider]	13.0	0.7337	230.3362
Rigging Failure [All Other Responsibilities] [Service Provider]	67.0	4.1131	1091.3816
Signaling [All Other Responsibilities] [Service Provider]	35.0	2.1088	580.8999
Two Block [All Other Responsibilities] [Service Provider]	22.9347	1.3541	388.4614
Unstable/Dropped/Lost Land [All Other Responsibilities] [Service Provider]	222.3365	13.8492	3570.3740

Research Question 2 asked, "How can the use of crane accident causation factors assist and improve the development of more effective risk management strategies to improve crane safety?" This question is a mixed method one with quantitative and qualitative methods used. There is no hypothesis that can be retained or rejected due to the lack of quantitative statistics. There were 1071 occurrences of contributors to accidents out of 169 actual contributors. This is an average frequency of 6.33 (*SD* = 10.85). The most common are close to the mean and the rarest are far away from the mean on the bell curve or distribution.

The criterion chosen was approximately one standard deviation higher than the mean which is a frequency of 17 or higher to include more contributory factors to the crane accident information. As seen in Table 16, the contributory factors, meeting the criterion are Overload (*n* = 119, 11.4%), Improper Rigging (*n* = 32, 3.0%), Lack of Softeners (*n* = 26, 2.4%), Load Shifts when lifted (*n* = 23, 2.1%), Manufacturing Defect (*n* = 23, 2.1%), Operational Aid Turned off/disconnected (*n* = 28, 2.6%), Operator Failed to Follow Load Charts (*n* = 23, 2.1%), Sling Failure (*n* = 30, 2.8%), and Structural Failure (*n* = 31, 2.9%). As seen in Table 17, Load becomes one category out of eight (*n* = 131, 12.23%), Worker Inserts Body in Pinch Point(s) (*n* = 19, 1.8%) and Worker Walks Into Load (*n* = 21, 2.0%).

Table 16: Contributors to Accidents (n = 1071)

CONTRIBUTOR	FREQUENCY	PERCENT
Abuse- Lack of Maintenance	7	.7
Additional Load is Suddenly Applied	11	1.0
Alterations or Repairs	2	.2
Altered or Damaged A2B	3	.3
Block Rigged Incorrectly	1	.1
Boom Impact	7	.7
Boom Overhaul	1	.1
Boom Raising/Lowering/Extending	10	1.0
Boom Section Suddenly Reacts	2	.2
Boom Tip Snags on Stationary Structure	1	.1
BTH Rebounds/Moves After Lift	2	.2
Change Configuration- Jump	5	.5
Component Failure	3	.3
Connection Between Parallel Rails Fails	1	.1
Control of Load- No Tag Line	1	.1
Crane Improperly Setup on Rails	2	.2
Crane Out of Level	5	.5
Crane Re-Configuration	2	.2
Crane Struck by Other Equipment	1	.1
Crane Swing Lock Engaged	4	.4
Crane Travel with Load- No Outriggers	1	.1
Crane Travel- Impacts Stationary Object	2	.2
Crane Unleveled	2	.2
Crane was Rigged Improperly	2	.2
Damage to Load	2	.2
Defective/Damaged Rigging	5	.5
Design Defect	3	.3
Dismantling	14	1.3
Displaced/Damaged Softeners	1	.1
Dynamic Load Applied to Rigging	1	.1
Dynamic Loading	13	1.2
Erection	5	.5
Failed Collar Rigging- Drop	1	.1
Failed Component- Lug	3	.3
Failed Rigging	2	.2
Failure at Landed Load	2	.2
Failure of a Wire Rope or Pendant	1	.1
Failure to Land Block Prior to Booming Down	5	.5

Table 16, cont.

CONTRIBUTOR	FREQUENCY	PERCENT
Foundation Design	1	.1
Foundation Failure	7	.7
Ground Support Issues	2	.2
High Boom- Into Backstops	13	1.2
Improper A/D Procedures	13	1.2
Improper Adjustment to Hook/Keeper	1	.1
Improper Crane Operation- Abuse	2	.2
Improper Dunnage for Outriggers	3	.3
Improper Inspection Procedures	2	.2
Improper Maintenance/Repairs	2	.2
Improper Removal of Pins	10	.9
Improper Rigging	32	3.0
Improper Stowage of Boom	2	.2
Improper Vanning	3	.3
Insufficient- Removed CW	7	.7
Lack of Softeners	26	2.4
Landed Load Cannot be Supported by Structure	2	.2
Landed Load Not Properly Braced	12	1.1
Landed Load Slides on Sloped Surface	1	.1
Landed Load Snagged/Pulled Off Support	2	.2
Lifting Device Failed	1	.1
Load Block Not Placed on Ground	1	.1
Load Buckles Due to Improper Rigging Attach	5	.5
Load Disengages From BTH	6	.6
Load Drifts Away from Crane	4	.4
Load Drops Due to Mechanical Failure	13	1.2
Load Is Rigged Below the C.G.	8	.7
Load Landed and Displaced by Crane Movement	2	.2
Load Not Properly Braced Prior to Lifted	11	1.0
Load Pushed/Pulled-Imbalance	16	1.5
Load Rotates	2	.2
Load Separates/Fails	7	.7
Load Shifts When Lifted	23	2.1
Load Shifts While Re-Rigging	4	.4
Load Shifts/Slides-Strikes/Displaces Load	5	.5
Load Slides Out of Rigging	16	1.5
Loss of Tie-In Support	1	.1
Lost Load- Stability	8	.7
Lug or Attachment Point on Load Fails	9	.8
Maintenance Issue	10	.9
Maintenance Issue- Corrosion	3	.3

Table 16, cont.

CONTRIBUTOR	FREQUENCY	PERCENT
Manufacturing Defect	23	2.1
Manufacturing Issue	2	.2
Mat Displacement	2	.2
Mechanical Failure- Maintenance	16	1.5
Mechanical Failure- Manufacturer	3	.3
Moving Climbing Frame	3	.3
Moving Crane- Change Configuration- Boom/Jib	5	.5
No A2B Installed	1	.1
No Outriggers- Boom Extended- No Load	2	.2
No Outriggers- Boom Extended -Upper Swung- No Load	3	.3
No Tag Line	5	.5
Non-Certified/Tested Rigging	2	.2
Operational Aid Turned Off/Disconnected	28	2.6
Operational Issues	2	.2
Operational- Securement	3	.3
Operational- Travel	4	.4
Operator Directed to Land the Load	8	.7
Operator Failed to Follow Load Charts	23	2.1
Outrigger Down- Snags	1	.1
Outrigger Failure- Soil	6	.6
Outrigger Failure- Structural	5	.5
Outriggers Not Extended	18	1.7
Overload	119	11.4
Overloaded- Load Testing- Certification	1	.1
Overridden	3	.3
Overridden LMI Or A2B	6	.6
Overridden- A2B	7	.7
Part of Load Comes Free- Pipe	3	.3
Part of The Load Line Assembly Fails	10	.9
Prior Damage/Repair to Boom/Jib	11	1.0
Pull on Stuck Load	2	.2
Pulling a Load-Lateral Load at Tip	4	.4
Rigging Comes Unhooked	14	1.3
Rigging Hooks/Snags	1	.1
Rigging Snags/Displaces Load	12	1.1
Side Loaded	15	1.4
Signals	2	.2
Sling Failure	30	2.8
Soil Failure/Trench/Slope	9	.8

Table 16, cont.

CONTRIBUTOR	FREQUENCY	PERCENT
Stuck Load	11	1.0
Structural Failure	31	2.9
Sudden Release of Stuck Load/Vibe Hammer	2	.2
Support Falls- Worker Falls	8	.7
Supporting Brace is Removed	1	.1
Swing- Dynamic Loading	3	.3
Tag Line Snags	4	.4
Tie-Down Design	2	.2
Tie-In Design	1	.1
Tower Crane Unbalanced during Jump	1	.1
Tracks Not Extended	2	.2
Tracks Not to Tolerances	1	.1
Travelling the Crane-Drive/Rail	7	.7
Travelling with a Suspended Load	6	.6
Travelling with Load	2	.2
Two Block-Manufacturer Design Issue	2	.2
Unbalance-Improperly Rigged	10	.9
Uncontrolled Load Impacts Object- Damage	1	.1
Unsecured- Wind	4	.4
Unstable Landing Area for Load	3	.3
Upper Locked- No Rotation	2	.2
Upper Not Locked-Rotates	4	.4
Use by an Unauthorized Person	7	.7
Wind	12	1.1
Wind Loading- Boom/Tower	14	1.3
Wind Loading- Load	4	.4
Wind/ICE	1	.1
Worker Caught in Wire Rope	3	.3
Worker Falls from Boom/Crane	2	.2
Worker Inserts Body into Pinch Point	4	.4
Wrong Setup- Mode	3	.3
Wrong Setup-Mode- LMI	3	.3
Wrong Setup- Mode- A2B	4	.4
Wrong Setup- Mode- LMI	3	.3
Wrong Weight- By Others	3	.3
Wrong Weight- Demolition	4	.4
Wrong Weight- Fluids/Materials in Load	2	.2
Wrong Weight- Operator	3	.3
Wrong Weight- By Others	12	1.1
Wrong Weight- Demolition	3	.3
Wrong Weight- Fluids/Materials in Load	4	.4

Table 16, cont.

CONTRIBUTOR	FREQUENCY	PERCENT
Wrong Weight- Not Known	10	.9
Wrong Weight- Operator	9	.8

Table 17: No Accident, but Injuries (n=1071)

INJURY	FREQUENCY	PERCENT
No Injury	756	70.6
Crane Struck by Other Equipment	2	.2
Hit by Part of the Crane	9	.8
Hook or Rigging Becomes Disengaged	3	.3
Improper Crane Design	1	.1
Inadvertent Contact with Controls	1	.1
Lack of Maintenance of The Crane	2	.2
Load	8	.7
Load Drifts/Rotates	23	2.1
Load Drops	6	.6
Load Falls After Being Placed	15	1.4
Load Is Snagged by Another Portion of Load	4	.4
Load Pushed/Pulled	17	1.6
Load Strikes a Worker	48	4.5
Load Strikes and Causes Other Items to Collapse	19	1.8
Maintenance	7	.7
Operational	5	.5
Part of Load Comes Lose/Shifts-Pipe	4	.4
Portion of Boom or Crane Falls	1	.1
Portion of Crane Comes Loose Striking Worker	4	.4
Portion of Load Not Attached-Falls and Strikes Worker	7	.7
Premature Removal or Inadequate Connectors-Binder	9	.8
Rebar Cage/Mat Collapsed- Lack of Bracing	2	.2
Removal of Binders with Pipe-Flies Off	1	.1
Rigging/Slings/Hook Snags Load/Object	7	.7
Stuck Load Suddenly Releases	1	.1
Tag Line Snags	3	.3
Unauthorized Personnel in Lift Zone	5	.5
Unintended Movement of The Crane	2	.2
Unintended Operation of BTH	2	.2

Table 17, cont.

INJURY	FREQUENCY	PERCENT
Wind	2	.2
Worker Caught in or Struck by Wire Rope	5	.5
Worker Caught or Struck by Outrigger	5	.5
Worker Climbs on Load	12	1.1
Worker Crushed/Run Over by Crane	9	.8
Worker Inserts Body in Pinch Point(s)	19	1.8
Worker Moves Portion of Crane- Pinched	7	.7
Worker Snagged by Load- Non-Accidental	1	.1
Worker Snagged by Tag Line/Wire Rope	1	.1
Worker Struck by Ball or Block	10	.9
Worker Struck by Crane Swing	5	.5
Worker Walks into Load	21	2.0

4.7 Chapter Conclusion

The original database was in Microsoft Excel and contained 108 variables involved in 701 crane accidents from 1983 to 2017 crane accidents. The criterion of what needs to have happened to include a crane accident case was a three-fold process. First, by expert consensus, it was agreed that a minimum number of sources for all cases that "qualified" to be input into the databases needed to be operationalized. At least one outside source of information not prepared by the research was required to be included in the study. Further, an actual video of the accident, of which there were many, could supplement for an outside source. At least three of the following were the primary sources of information relied upon for each evaluation.

A population size of total crane accidents over the 35-year period was calculated based on fatal crane statistics documented between 1992 and 2016. Average annual death rates were 6.36 for the study and 34.72 per OSHA. A sample size of 701 accidents with an estimated population of 5,833 would yield a confidence level of 99% with a 4.55%

margin of error. If a 20% factor is applied for unreported non-fatal accidents, the estimated total would yield an estimated population of 7,000 accidents. A sample size of 701 would equate to a 99% confidence level with a 4.6% margin of error.

On Crane Capacity, an interesting trend occurs with 15 to 99 tons being involved in 380 crane accidents followed by 100 to 199 tons and 200 to 299 tons, where the lowest numbers of accidents occur with the highest tonnage. Thirty accidents at 300 to 599 tons and eight at greater than 600 tons. Next, First Crane Type, Mobile Hydraulic, and Track-Lattice accounted for 346 of all crane accidents. On the other hand, 22 other First Crane Types account for 54.3% of all crane accidents. For Second Crane Type, the same pattern emerged with Mobile Hydraulic and Track-Lattice being involved in the most accidents and three other types following in low. Further investigation into Mobile Hydraulic and Track-Lattice Cranes is suggested.

Multinomial logistic regression was used to explain data and the relationship between one nominal dependent variable and one or more continuous-level (interval or ratio scale) independent variables (Menard 2010). This statistic was run to examine Research Question 1, which stated, "Do the duties and responsibilities established by ASME B30.5 appropriately address associated causes of crane accidents by all responsible parties?" Additionally, this statistic was run to determine if the null hypothesis (below) was retained. All six assumptions were met.

Multinomial regression was run using the dependent variable of 1-Person Accident and 1-Person Primary Responsibility, and the result was statistically significant, and this meant that 74.3% of one-person accidents were explained by one-person responsibilities. The null hypothesis was rejected, and the duties and responsibilities established by ASME B30.5 do address appropriately associated causes of crane accidents by all responsible parties.

Table 6, showed the accident type and the responsible party from 1-person accidents. Starting with an accident on assembly/disassembly, the presence of a Service Provider (SP) caused the Odds Risk Ratio (ORR) to rise from 1.0 to 6485.089 times the probability of an accident occurring. For the SP, the range of accidental probability range goes, for an accident to occur goes from 2.978 (Worker Contacted by Load No Accident) to 1,186,610,348,000,000,000.000 (Unstable/Dropped/Lost Load). The rest of the responsibilities increase accidents somewhere between 2.0 to 16.0). The data from 2 and 3-person accidents and 1 and two responsible were not statistically significant.

Research Question 2 asked, “How can the use of crane accident causation factors assist and improve the development of more effective risk management strategies to improve crane safety?” This question is a mixed method one with quantitative and qualitative methods used. There is no hypothesis that can be retained or rejected due to the lack of quantitative statistics. There were 1071 occurrences of contributors to accidents out 169 actual contributors. This is an average frequency of 6.33 (SD = 10.85). The most common are close to the mean, and the rarest are far away from the mean on the bell curve or distribution.

The criterion chosen was approximately one standard deviation higher than the mean which is a frequency of 17 or higher to include more contributory factors to the crane accident information. As seen in Table 16, the contributory factors, meeting the criterion are Overload, Improper Rigging, Lack of Softeners, Load Shifts when lifted, Manufacturing Defect, Operational Aid Turned off/disconnected, Operator failed to follow load charts, Sling Failure, and Structural Failure. As seen in Table 17, Load becomes one category out of eight, Worker inserts body in pinch point(s), and Worker walks into the load (n = 21, 2.0%).

Chapter 5 – Conclusions and Recommendations

Accident analyses, particularly crane accident analyses, have been limited in number and in scope. Existing research regarding crane accident information has often been limited to fatality data, made available through OSHA-generated IMIS data. IMIS data lacks analyses concerning accident causation but rather are more concentrated on violations of code and deviations from standard industry practices.

The researcher of this study provided a large database, which included research collected over a 30-year period, that comprised information developed through forensic analyses of crane accidents which would have conclusive data associated with causation and assigned responsible parties in order to fill the gap from typical use of IMIS data. Through analyzing the data available, from 701 forensically evaluated crane accidents, the researcher has provided recommendations for future research and practice based upon his findings.

After statistical testing, during which the researcher analyzed crane accident data, the researcher noted key causative factors that influence crane accidents, particularly those involving injuries and fatalities. To further extend the research findings presented, the research conducted qualitative analyses and has made recommendations based upon said analyses. Chapter 5 presents the researcher's conclusions and recommendations that have been made based upon the study's guiding research questions. It is the hope of the researcher that recommendations made will assist all industries that use cranes and thereby reduce accidents, injuries, and fatalities if applied.

5.1 Research Question 1

Multinomial logistic regression methods have assisted researchers, including this study's researcher, in explaining the data and the relationships between single nominal dependent variables and one or more continuous-level (i.e., interval or ratio scale) independent variables (Menard 2010). This method of analysis addressed Research Question 1, which stated, “Do the duties and responsibilities established by ASME B30.5 appropriately address associated causes of crane accidents by all responsible parties?” Also, this approach sought to determine if the null hypothesis (below) was retained.

$H_0$1. The duties and responsibilities established by ASME B30.5 (Figure 8) do not address appropriately associated causes of crane accidents by all responsible parties.

H_A1. The duties and responsibilities established by ASME B30.5 do address appropriately associated causes of crane accidents by all responsible parties.

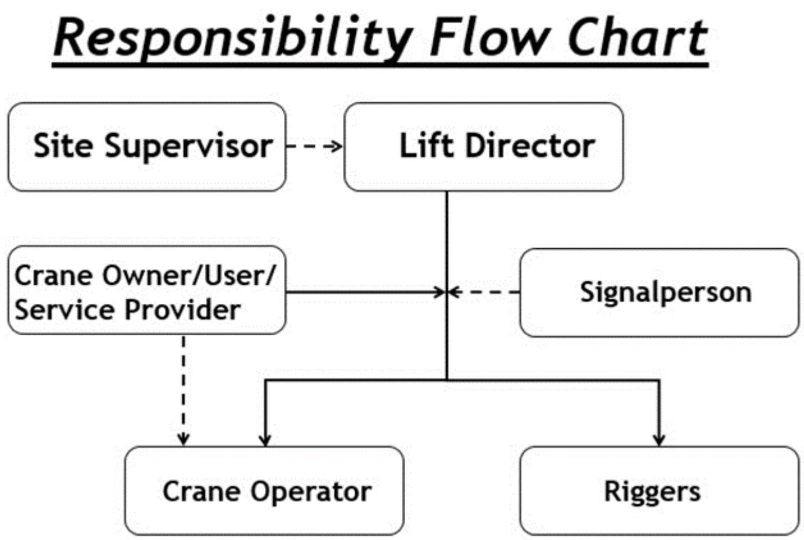

Figure 8: Responsibility Flowchart

Multinomial regression was run using the dependent variable of 1-Person Accident and 1-Person Primary Responsibilities. The result of the multinomial regression was that the Nagelkerke R^2 was equal to .743 and was found to be significant at $X^2(190) = 947.692$, $p < 0.0001$ (Table 13). This result means that 74.3% of 1-Person Accidents were explained by 1-Person Primary Responsibilities. The null hypothesis, therefore, is rejected, thus the duties and responsibilities established by ASME B30.5 appropriately address associated causes of crane accidents.

5.1.1 Research Question 1 Recommendations

Analyses indicate that the duties and responsibilities of crane lift personnel, as specified by ASME, are effectively addressed. However, several issues that were identified during the study direct attention to Manufacturers of Loads/Lifting Instructions/Lugs and Mechanical/Maintenance/Inspection Issues. Currently, there are no specific requirements for Manufacturers of Loads to provide any lifting instructions or sufficient information regarding the load, particularly the location of the center-of-gravity, to enable crews to control and lift loads safely without multiple test lifts. Additionally, accident analysis confirmed that while some manufacturers do provide lifting lugs, unfortunately, too often these lifting lugs are located below the center-of-gravity, thereby resulting in a condition that results in suspended load instability or even "flipping," during hoisting process.

Crated cargo that is off-loaded from ships often arrives with no information regarding weight and center-of-gravity designations. The Lift Director, who is responsible for controlling the lift, must make determinations and provide instructions for proper rigging. The Lift Director needs proper and complete instructions for every load to be lifted and placed. A secondary responsibility of the Lift Director should be to confirm the availability of handling instructions/information. Providing this information, regarding handling instructions, would be the primary responsibility of the Load Manufacturer(s). Through access to and proper use of this information, it is likely that there will be a reduction of occurrences of unstable, dropped, and lost loads, which was noted as one of the most frequent types of accidents identified in this study.

Mechanical/Maintenance/Inspection Issues, which are addressed within the ASME standard, are currently limited to personnel qualifications. ASME standards are limited regarding procedures required to complete effective and proper crane inspections, particularly in regard to annual inspections. Based upon study results of accident causation, the researcher recommends that Crane Manufacturers provide a detailed checklist, which specifies proper instructional methods for crane operations. Though Crane Manufacturers do detail most mechanical issues and maintenance items, as outlined in Maintenance and Operations/Operator's Manual, inspections are only confined to a list of items. Inspection issues not identified in the manuals provided are an ever-growing issue, specifically given the complexity of cranes. Therefore, it is recommended that another responsibility requirement, for maintenance/inspection, involve the creation of a manual detailing information about mechanical, maintenance, and inspection issues and specific procedures for each.

One of the most difficult inspections involved in crane operations is the "running" of the wire rope, which is located in the boom hoist assembly and load line. Qualified personnel must follow specific guidelines set forth by the ASME standard, noted by the manufacturer, for crane and wire rope operations. Guidelines should be created, which identify critical inspection items, as well as proper methods for conducting those inspections. Given this lack of guidelines, many inventive inspection methods have been created by inspectors without any specific guidance from the wire rope or Crane Manufacturers. Due to the difficulty of inspecting wire rope, it is believed that an estimated useful life should be provided by the wire rope manufacturer.

The researcher, based upon the study findings, has identified that one of the most frequent types of major accidents is due to Unstable/Dropped/Lost Load. A number of these incidents are related to load manufacturer failures, since these manufacturers do not provide adequate information/direction as to how to rig the load, which will thereby prevent unintended movement once the load is in the air. Serious incidents associated with these types of accidents include workers being struck when the load was being lifted or when workers attempted to grab or hold the load to prevent its movement. Load movement, or drifting, is common in the crane industry due to boom deflections, particularly hydraulic crane booms. Normal procedures associated with load movement include raising the load several inches (normally 6-12 inches) to ensure the load is stable before continuing with the lift. Rigging personnel must stand clear of the load to prevent getting struck if the load moves/drifts. Currently, Lift Directors are responsible for the placement of personnel and for deciding if tag lines should be used. Lift Directors should be provided with detailed instructions regarding precise details concerning load movements, specifically in regard to the potential for the load striking the workers. These directives are especially important when project personnel are in tight quarters during which the prevalence of a worker being crushed is increased. Similar directives should be provided in Rigger responsibilities so they understand the importance of maintaining a distance from the load to avoid potential crushing points should the load drift/move.

5.2 Research Question 2

Research Question 2 utilized a quantitative analysis to answer the question of, "How can the use of crane accident causation factors to assist and improve the development of more effective risk management strategies to improve crane safety?" As part this analysis, the researcher performed multinomial regressions to determine relative risks associated with various crane operations. Relative risks ratios assess the probability of an event occurring by comparing the incident or risk associated with an event to the exposure of parties or lack of exposure of parties. Relative risk is based upon the incidence of an event occurrence since participants are already identified and their corresponding exposure status is identified.

Large odds ratios are far more inaccurate than relative risk ratios, as it is always further away from 1.0 then relative risk (Andrade 2015). So, the suggestion is to use relative risk when odds ratios are very large (Andrade 2015), such as Assembly/Disassembly where the ORR fell from 6485.089 to the RR of 73.0 (Tables 14 and 15). The 1-Person Accident Types were the largest, as noted in Table 14, which were converted to RR. Within Table15, one can clearly see the drop-in estimation. Relative risk ratios should be used in Table 15 since they are more accurate. In Table 15, the highest risk situation was Crane Overturn involving the fault or cause of the Service Provider, which was 335.0 times greater, in regard to risk, than other accidents identified. The lowest risk situation was at 13.0 times greater with Personnel Basket Failure and the involvement of a Service Provider. Risk Ratio for an unstable, dropped, or lost load is 222.3365 times greater when a Service Provider is involved. The aforementioned findings denote specific hazards associated with Service Providers who are assigned to a new worksite and are working alongside a new crane, which often occurs on many projects in which a crane and operator are rented to perform a lift.

Well documented research has noted that when changes in a work environment occur, there is an increased probability of accident occurrences. Accidents affect workers and the public (Attwood et al. 2006; Georgiadou 2001; Hofmann et al. 1995; Papadopoulos 2003; Rasmussen 1997; Uth and Wiese 2004, 2006; Zwetsloot and Hale 2002; Zwetsloot et al. 2007). Research studies also indicate that subcontractors, such as Service Providers who conduct work/tasks on job sites, are prone to major accidents, specifically due to a dearth of training, as well as inadequate monitoring of work safety practices (Dechy et al. 2004; Uth and Wiese 2004). When companies use subcontractors in high risk workplaces (i.e., chemical plants, construction sites, maintenance worksites, etc.) it is often more difficult to coordinate work activities, to implement OSHA v measures, and to mitigate site hazards (Papadopoulos et al. 2010). The utilization of subcontractors may result in serious accidents, thereby affecting public safety given the worksite hazards present.

An additional factor that can influence the frequency of job site injuries is the employment of agency, seasonal, on-call, and new/inexperienced workers. Occupational Health and Safety investigations have found that accident rates for such workers can be substantially more than accident rates for seasoned employees (Underhill and Quinlan 2011). Workers who have been on the job for short periods of time are more frequently involved in accidents. Heinrich et al. (1950) orated that accidents result from unsafe acts (i.e., deviations from normally accepted safety procedures) or unsafe conditions (i.e., deficiencies in machines and materials). Researchers have found that 88% of accidents are the result of unsafe acts and 10% of accidents are due to unsafe conditions (Heinrich et al. 1950). Garrett and Teizer (2009) noted that human error serves as the primary reason for as many as 80% of all accidents in high-risk industries (i.e., construction, mining, and nuclear power plant operations). Unsafe behavior and unsafe conditions are recognized as the primary reasons for construction site accidents (example: when workers are not familiar with crane operating procedures; Wang et al. 2015).

5.2.1 Research Question 2 Recommendations

The Service Provider situation is unique, especially considering that these individuals often work in new locations and with a new crew (comprised of new workers with limited prior experience). Below are some of the work environment and crew changes that a Service Provider is exposed to during contracted projects:

- Changing worksites (environments) on a regular, if not daily, basis.
- Working in many different industry sectors, which all have different requirements and standards of operation.
- Working with various types of loads, on a regular basis, therefore preventing stability.
- Long, unscheduled periods of work.
- Locations that are less than optimal for the assigned lift, which include:
  - Spatial conflicts (i.e., oversized or undersized cranes).
  - Larger projects that require considerable planning.
- Working under the sole direction of the Lift Director, which means:
  - There is an infrequency of pre-lift meetings conducted to ensure that workers know their roles and responsibilities.
  - Service Providers are rarely involved in the lift planning process.
  - Service Providers are given incorrect weight or inaccurate project information.
- Clients and/or crews often are unsophisticated/untrained regarding lifting operations and procedures.
- Often times, the assignment involves working with inexperienced crews, especially when on smaller jobs.
  - It is not uncommon for new riggers, who are inexperienced, to get too close to the load.

- Due to inadequate training, loads are often rigged incorrectly and become unstable (i.e., loads drift, flip, or rotate).

- Service Providers are often required to work with crew members who they have not worked with before.
- New Signal Persons, assigned to the project, must ensure they understand signals and therefore, these individuals often rely on the Lift Director to identify all site hazards.

Through conducting this analysis, the researcher has identified two critical issues that need to be addressed. As noted in the study findings, when Service Providers coordinate crane operations, there is often an increased frequency of incidents, specifically due to Unstable/Dropped/Lost Load. Worksite changes, which are frequent in nature, are problematic for Service Providers. In fact, when a Service Provider is working with a new crew, all inherent dangers must be addressed. One's ability to recognize such dangers is compounded by the complexities of working with new individuals on a site that they are unfamiliar with. A Service Provider often times has little formal control, on the worksite, and therefore, he/she must rely on the persons who are conducting the lift to ensure that all parties understand the lifting plan. Often times, pre-lift meetings are held to ensure that the lift crew, consisting of personnel from different trades/industries, are familiar with the project. However, given trade/industry differences, as well as little familiarity in regard to party roles/responsibilities, it is difficult to conduct a safe lift. It is highly recommended that all lifts be preceded by pre-lift meetings, particularly when a Service Provider is involved. An effective pre-lift meeting identifies every party and details associated roles and responsibilities that are discussed and assigned prior to the lift. Recommendations for conducting an effective pre-lift meeting should include the following:

- Confirmation of the qualifications and certifications of all crane lift personnel.
- Overview of the load handling activity.
- Conducting a Job Hazard Analysis regarding the lift (including worker positioning, potential obstructions along the load path- crane swing, personnel positioning, and personal protection equipment; PPE).
- Confirmation that the load path does not pass over any site personnel.
- Discussion regarding the load, specifically focusing on confirming that proper rigging equipment and rigging methods are used.
- Discussion of the sequential steps associated with the lift, as well as the roles and responsibilities of all parties, which includes discussion of the:
    - Placement and locations of personnel during the lift.
    - Confirmation of the load's stability.
    - Required lift signals.
    - Signal Person transfer from the ground to final location.
    - Confirmation that the landing area is sufficient to support the load.
- Identification of communication methods (i.e., hand signal or wireless) between the crew and the operator.
- Discussions of Stop Work authority and processes, during the lift process, if anyone detects a hazard not previously identified.
- Confirmation by all crew members that they understand their roles and agree to the plan set forth.
- Discussions concerning contingency options if the lift does not go as planned.

Unfortunately, verbal communication efforts among the Lift Director, Lift Crew, and the Crane Operator, who is contracted by a Service Provider, are lacking, as these individuals have little time to interact and understand the roles of all parties. The use of a pre-lift meeting would not be disruptive, thereby affording all crew members, as well as the Crane Operator, with the opportunity to discuss the steps of the lift and load placement locations. From a Service Provider's standpoint, the pre-lift meeting is a critical need, especially as confirmed by this research study, which notes that inherent high risks are present for Service Providers involved in projects due to lacking experience/engagement with the crew and worksite.

5.3 FUTURE RECOMMENDATIONS

Crane accident analyses, based on forensic causation techniques, is a promising and undeveloped area of research. The use of a large database provides detailed information about crane accident causes, thereby enabling the potential implementation of corrective measures to improve crane safety operations. Recommended future study areas include:

- Addressing initiating and contributing factors that have led to repeated and/or similar accidents.
- Development of more proactive inspection procedures and load stability evaluations.
- Examination of what safety issues were present that led to accidents/injuries when there was no load on the hook.
- Examination of injuries and fatalities when, by this researcher's definition, an accident did not occur.
- A study of number and types of accidents associated with:
    - Union versus non-union operators.
    - Value and size of the project.

5.4 CHAPTER CONCLUSION

Research findings have demonstrated that many parties must be involved in the planning and execution of crane lifts. As demonstrated by the findings of this study, it is imperative that all lift planning information be provided to all crew members and that all crew members agree with the plan before initiating a lift. Accident trend examinations have indicated that certification procedures have improved, in regard to Crane Operator responsibilities. Additionally, through analyses, the researcher has identified that personnel involved in crane lifts, such as the Lift Director, need further direction and education, specifically in regard to their roles, responsibilities, training, etc. It is the hope of this researcher that future studies explore how crane accidents can be minimized/prevented, thereby decreasing the likelihood of accidents, injuries, and deaths. Results of this study, as well as those to follow, should be provided to national standards groups and to government agencies for their consideration.

Appendix A - List of Information Collected

QUESTION NUMBER	QUESTION	ANSWER
1	Year of Accident	
	Case ID No	
	Haag Job Name	
	Haag Job Number	
2	Date of Incident	
3	Time of Incident	
4	City	
	State	
5	Number of Injuries	
6	Injury by Trade Ironworker Management No Injuries Oiler Operator Other Field Personnel Pedestrian/Bystander Rigger Signal Person	
7	Union	
	Non-Union	
8	Number of Deaths	
9	Deaths by Trade Ironworker Management No Deaths Oiler Operator Other Field Personnel Pedestrian/Bystander Rigger Signal Person	
10	Estimated Property Damage	
11	Estimated Equipment Damage	
12	Category/Sector Arborist/Logging/Agriculture Commercial Construction Highway/Road & Bridge Industrial/Refining Industry Manufacturing Industry	

	Marine Industry Mining Industry Oilfield- Land Base Oilfield- Offshore Residential Construction	
13	Type of Lift Being Performed Assembly/Disassembly Crane Not in Use Crane Travel/Booming/Swinging Critical Lift Demolition General Lift Lifting Personnel/Basket Standard Production Lift	
14	Type of Crane Operation Bare Lease/Operated Borrowed or Unauthorized Use Owned/Operated by User Service Provider-Operator	
15	Type of Work Being Performed Arborists Assembly/Disassembly Concrete Placement Concrete Tilt- Wall Construction Crane Not in Use Demolition Drilled Shafts Handling Formwork Lifting Personnel Maintenance on Crane Materials Handling- Miscellaneous MEP Equipment/Oilfield/Transformers Pile Driving Pile Extraction Placing K-Rails/CTBs/Jersey Rails Power/Wind Generators Pre-Cast Girders/Beams/Tees Setup-Configure-Re-Configure Hydros Ship Loading/Unloading Steel Erection-Steel Girders- Rebar Structural Steel Platforms Swinging/Booming/Operations- No Load Transmission Towers- Cell Towers Traveling with Load Traveling with No Load Wood Beams or Trusses	
16	Accident Types Assembly/Disassembly Boom/Jib Collapsed	

	Boom/Jib Dropped Crane De-Railed Crane Overturn Landed Load-Stability Failure Other Personnel Basket Accident Power Line Contact Rigging Failure Signaling Slewing Assembly Failure Trip/Slip/Fall/Jump from Crane Two Block Unstable/Dropped/Lost Load Worker Contact by Crane- No Accident Worker Contact by Load- No Accident	
17	Load-No Load Load on the Hook No Load on the Hook	
18	Property-Equipment Damage Damage to Equipment/Crane Damage to Property Damage to Property & Equipment No Damage to Property or Equipment	
19	Injuries-Deaths Deaths Injuries Injuries & Deaths No Deaths No Injuries or Deaths No Injuries	
20	Description of Accident	
21	Conclusions of Causes	
22	Resources Used Deposition Depositions/Statements of Witnesses Document Review Incident Report Provided Inspection OSHA File Provided Photographs Testing/Modeling/Animation/Video of Incident Trial Written Report	
23	Primary Responsibilities Crane Manufacturer Crane Operator Lift Director Manufacturer of Load/Lifting Instructions/Connections Points	

	Mechanical/Maintenance Issue Other Owner/User Rigger Service Provider Signal Person Site Supervisor	
24	Secondary Responsibilities Not Applicable Crane Manufacturer Crane Operator Lift Director Manufacturer of Load/Lifting Instructions/Connections Points Mechanical/Maintenance Issue Other Owner/User Rigger Service Provider Signal Person Site Supervisor	
25	Crane Manufacturer	
26	Crane Type Boom Truck Derrick Gantry Knuckle Boom Mega Crane Mobile Hydraulic Mobile Lattice Mobile RT Overhead Shop Built Special- Gin Pole Special- Launching Girder Special- Log Boom Special- Marine Special- Side Boom Special- Straddle Crane Tower- Hammer Head Tower- Luffing Tower- Pedestal Tower- Self-Erect Truck- Hydraulic Track- Lattice	
27	Crane Model (UNK if not known)	
28	Serial Number (UNK if not known)	
29	Year of Manufacture (UNK if not known)	
30	Crane Capacity	

	Less than 2 Tons 2 to 14 Tons 15 to 99 Tons 100 to 199 Tons 200 to 299 Tons 300 to 599 Tons Greater than 600 Tons	
31	Boom Length 0 to 50 Feet 51 to 100 Feet 101 to 150 Feet 151 to 200 Feet 201 to 250 Feet 251 to 300 Feet 301 to 350 Feet 351 to 400 Feet Greater than 400 Feet	
32	Outriggers Fully Extended Partially Extended Fully Retracted Not Applicable	
33	Lift Data 1 Operator Certified Operator Not Certified	
34	Lift Data 2 Written Lift Plan No Written Lift Plan	
35	Lift Data 3 Pre-Lift Meeting No Pre-Lift Meeting	
36	Lift Data 4 Not Applicable Blind Lift Maintenance on Crane	
37I	Crane Stability- Overturn Initiating Not Applicable Abuse- Lack of Maintenance Additional Load is Suddenly Applied Altered or Damaged A2B Crane Out of Level Failed Component-Lug Failure at Landed Load Foundation Failure Improper A/D Procedures Insufficient- Removed CW Lifting Device Failed Landed Load- Stability	

	Maintenance Issue Manufacturing Defect Mat Displacement No Outriggers- Boom Extended- No Load Outrigger Failure- Soil Outrigger Failure- Structural Outriggers Not Extended Overload Overridden- A2B Pulling a Load- Lateral Load at Tip Signals Slope Failure Soil Failure/Trench/Slope Structural Failure Stuck Load Swing- Dynamic Loading Travelling the Crane- Drive/Rail Travelling with a Suspended Load Upper Not Locked- Rotates Use by an Unauthorized Person Wind Wrong Setup- Mode- A2B Wrong Weight- By Others Wrong Weight- Demolition Wrong Weight- Fluids/Materials in Load Wrong Weight- Not Known Wrong Weight- Operator	
37C	Crane Stability- Overturn Contributing Not Applicable Abuse-Lack of Maintenance Additional Load is Suddenly Applied Altered or Damaged A2B Crane Out of Level Failed Component- Lug Failure at Landed Load Foundation Failure Improper A/D Procedures Insufficient- Removed CW Lifting Device Failed Landed Load- Stability Maintenance Issue Manufacturing Defect Mat Displacement No Outriggers- Boom Extended- No Load Outrigger Failure- Soil Outrigger Failure- Structural Outriggers Not Extended Overload Overridden- A2B Pulling a Load- Lateral Load at Tip	

	Signals Slope Failure Soil Failure/Trench/Slope Structural Failure Stuck Load Swing- Dynamic Loading Travelling the Crane- Drive/Rail Travelling with a Suspended Load Upper Not Locked- Rotates Use by an Unauthorized Person Wind Wrong Setup- Mode- A2B Wrong Weight- By Others Wrong Weight- Demolition Wrong Weight- Fluids/Materials in Load Wrong Weight- Not Known Wrong Weight- Operator	
38I	Boom/Jib/Tower Collapse Initiating Not Applicable Abuse- Lack of Maintenance Additional Load is Suddenly Applied Altered or Damaged A2B Boom Impact Crane Struck by Load- Non-operational Crane was Rigged Improperly Dynamic Loading Engineering Issue- Demo Failed Component- Lug Failure at Landed Load Foundation Design High Boom- Into Backstops Maintenance Issue Manufacturing Issue Operational Aid Turned Off/Disconnected Overloaded Overridden A2B Prior Damage/Repair to Boom/Jib Side Loaded Structural Failure Stuck Load Sudden Release of Hammer Tie-In Design Use by an Unauthorized Person Wind Loading- Boom/Tower Wind Loading- Load Wrong Setup-Mode- A2B Wrong Weight- By others Wrong Weight- Demolition Wrong Weight- Fluids/Materials in Load Wrong Weight- Not Known	

	Wrong Weight- Operator	
38C	Boom/Jib/Tower Collapse Initiating Not Applicable Abuse- Lack of Maintenance Additional Load is Suddenly Applied Altered or Damaged A2B Boom Impact Crane Struck by Load- Non-operational Crane was Rigged Improperly Dynamic Loading Engineering Issue- Demo Failed Component- Lug Failure at Landed Load Foundation Design High Boom- Into Backstops Maintenance Issue Manufacturing Issue Operational Aid Turned Off/Disconnected Overloaded Overridden A2B Prior Damage/Repair to Boom/Jib Side Loaded Structural Failure Stuck Load Tie-In Design Use by an Unauthorized Person Wind Loading- Boom/Tower Wind Loading- Load Wrong Setup- Mode- A2B Wrong Weight- By Others Wrong Weight- Demolition Wrong Weight- Fluids/Materials in Load Wrong Weight- Not Known Wrong Weight- Operator	
39	Two Blocking Not Applicable Altered or Damaged A2B Manufacturing Defect No A2B Installed Operational Aid Turned Off/Disconnected Overridden Use by an Unauthorized Person Wrong Setup- Mode	
40	Assembly- Disassembly Process Not Applicable Change Configuration- Jump Dismantling Erection Moving Crane- Change Configuration- Boom/Jib	

41I	Assembly- Disassembly Initiating Not Applicable Ball or Block Falls during Assembly Brake Failure Crane Improperly Setup Failure of a Wire Rope or Pendant Manufacturing Issue Worker Caught in Wire Rope Worker Falls from Boom/Crane Worker Removes Wrong Pin	
42	E1-Worker Contacted by Crane- Accident Contributing Not Applicable Hit by Part of the Crane Maintenance Portion of Boom or Crane Falls Portion of Crane Comes Loose Striking Worker Worker Caught in or Struck by Wire Rope Worker Caught or Struck by Outrigger Worker Crushed/Run Over by Crane Worker Moves Portion of Crane- Pinched Worker Struck by Ball or Block Worker Struck by Crane Swing	
43	E2- Worker Contract by Load- Accident Contributing Not Applicable Crane Overturned Crane Struck by Other Equipment Hook or Rigging Becomes Disengaged Lack of Maintenance of the Crane Load Becomes Unstable when Lifted Load Drifts/Rotates Load Falls After Being Placed Load Is Snagged by Other Portion of Load Load Pushed/Pulled Load Strikes a Worker Load Strikes and Causes Other Items to Collapse Maintenance Issue on Lifting Device Operational Part of Load Comes Lose/Shifts-Pipe Portion of Load Not Attached- Falls and Strikes Worker-Demolition Premature Removal or Inadequate Connectors- Binders Rebar Cage/Mat Collapsed- Lack of Bracing Removal of Binders with Pipe- Flies Off Rigging Failure Disrupts Load Rigging/Slings/Hook Snags Load/Object Tag Line Snags Unauthorized Personnel in Lift Zone Wind Worker Inserts Body in Pinch Point(s) Worker Snagged by Load- Non-Accidental	

	Worker Walks into Load	
44	Worker Contacted by Crane No Accident Contributing Not Applicable Hit by Part of The Crane Maintenance Portion of Boom or Crane Falls Portion of Crane Comes Loose Striking Worker Worker Caught in or Struck by Wire Rope Worker Caught or Struck by Outrigger Worker Crushed/Run Over by Crane Worker Moves Portion of Crane-Pinched Worker Struck by Ball or Block Worker Struck by Crane Swing	
45	Worker Contacted by Load No Accident Contributing Not Applicable Crane Struck by Other Equipment Hook or Rigging Becomes Disengaged Lack of Maintenance of the Crane Load Becomes Unstable When Lifted Load Drifts/Rotates Load Falls After Being Placed Load Is Snagged by other Portion of Load Load Pushed/Pulled Load Strikes a Worker Load Strikes and Causes Other Items to Collapse Maintenance Issue on Lifting Device Operational Part of Load Comes Lose/Shifts- Pipe Portion of Load Not Attached- Falls and Strikes Worker-Demolition Premature Removal or Inadequate Connectors- Binders Rebar Cage/Mat Collapsed- Lack of Bracing Removal of Binders with Pipe- Flies Off Rigging Failure Disrupts Load Rigging/Slings/Hook Snags Load/Object Tag Line Snags Unauthorized Personnel in Lift Zone Wind Worker Inserts Body in Pinch Point(s) Worker Inserts Part of Body in Pinch Point Worker Snagged by Load- Non-Accidental Worker Walks into Load	
46I	Boom Dropped Initiating Not Applicable Boom Dropped During Erection Boom Dropped During Operation Jib Dropped During Erection Jib Dropped During Operation	
46C	Boom Dropped Contributing	

	Not Applicable Boom Hoist Brake Failure Boom Hoist Wire Rope Failure Boom Over Backwards- Stability Improper Inspection/Maintenance Jib Pendant Failure Jib Support Failure Manufacturing Defect Prior Damage to Boom Unauthorized Crane Operation Uncertified Rigging in Boom	
46JI	Jib Displacement Initiating Not Applicable Boom Extended- Pins Not Removed Failed to Follow Manufacturer's Instructions Improper Inspection/Maintenance Jib Bracket Failure Jib Erection- Operator Jib Erection- Rigger Jib Not Properly Secured to Side of Boom Jib Rigged Improperly Manufacturing Defect Pin Not Engaged Sufficiently Pins Not Removed Prior Damage to Jib Assembly Unauthorized Repairs Unauthorized Use Wrong Pins Removed	
46JC	Jib Displacement Contribution Not Applicable Jib Fell During Crane Travel Jib Fell During Erection- Mechanic Jib Fell During Erection- Operator Jib Fell During Erection- Rigger Jib Fell During Operation Jib Fell During Stowage- Mechanic Jib Fell During Stowage- Operator Jib Fell During Stowage- Rigger	
47I	Rigging Failure Initiating Not Applicable Component Failure Control of Load- No Tag Line Sling Failure Spreader Beam Failure Unbalance- Improperly Rigged	
47C	Rigging Failure Contributing Not Applicable Defective/Damaged Rigging Lack of Softeners	

	Non-Certified/Tested Rigging Unbalance- Improperly Rigged	
48I	Unstable/Dropped/Lost Load Initiating Not Applicable Brake Fails- Drops Load Failed Rigging Load Buckles Due to Improper Rigging Attach. Load is Rigged Below the C.G. Load Landed and Displaced by Crane Movement Load Not Properly Braced Prior to Lifted Load Shifts While Re-Rigging Load Shifts When Lifted Lug or Attachment Point on Load Fails Manufacturing Defect Mechanical Failure- Maintenance Mechanical Failure- Manufacturer Mechanical Failure- Repair/Replacement Operational Part of Load Comes Free- Pipe Part of the Load Line Assembly Fails Rigging Comes Unhooked Tag Line Snags Wind	
48C	Unstable/Dropped/Lost Load Contributing Not Applicable Failed Rigging Load Buckles Due to Improper Rigging Attach. Load is Rigged Below the C.G. Load Landed and Displaced by Crane Movement Load Landed and Unfolds When Landed Load Not Properly Braced Prior to Lifted Load Shifts While Re-Rigging Load Shifts When Lifted Load Strikes and Causes Other Items to Collapse Lug or Attachment Point on Load Fails Manufacturing Defect Mechanical Failure- Maintenance Mechanical Failure- Manufacturer Mechanical Failure- Repair/Replacement Operational Part of Load Comes Free- Pipe Part of the Load Line Assembly Fails Rigging Comes Unhooked Tag Line Snags Wind	
49	Power Line Contact Not Applicable Maintenance Operator- Travel	

	Operator- Operations Rigger Pulls Load Line into Power Static Electricity- Microwave Towers	
50	Slewing Assembly Failure Not Applicable Excessive Loading- Operations Excessive Loading- Wind Lightning Maintenance- Bolts Manufacturing Defect Repair	
51I	Crane Derailment Initiating Not Applicable Operational- Travel Unsecured- Wind	
51C	Crane Derailment Contributing Not Applicable Connection Between Parallel Rails Fails Maintenance Issue- Corrosion Manufacturing Defect Operational- Securement Operator Abuse Tracks Not to Tolerances	
52I	Landed Load- Stability Initiating Not Applicable Landed Load Cannot be Supported by Structure Operator Directed to Land the Load Operator Landed the Load Unstable Landing Area for Load	
52C	Landed Load Stability Contributing Not Applicable Landed Load Cannot be Supported by Structure Load Becomes Unstable After Disconnected Load is Not Braced and Falls Unstable Landing Area for Load	
53	Lifting Personnel-Basket Not Applicable Basket Failed Basket Not Certified/Tested Basket Struck Object Improper Assembly of Crane Load Line Comes Off Sheave No Trial Run Rigging/Load Line Failure Wind Worker Not Tied Off	
54	Trip/Fall/Jump From Crane Not Applicable	

	Personnel Falls/Jumps from Platform Personnel Jumps from the Crane Personnel Trips/Slips While on the Crane	
55	Signaling Not Applicable Failure to Have Clear Visibility of Load Failure to Watch Hook/Block Exit Structure Wrong Signal	
56	Other Not Applicable Cracked Component Found During Inspection Other Object Strikes Crane Outrigger Damages Underground Utilities Worker Inserts Part of Body in Pinch Point	
57	Critical Lifts Not Applicable Change in the Lift Plan Operational Issues Plan Issues Rigging Site Controls Weather Wrong Weight	

Glossary

LIFT TYPES

Critical lift: Any lift utilizing multiple cranes is always a critical lift. Other criteria would be the weight of the equipment to be lifted as compared to the allowable lift, the swing area of the lift, the overall risk, difficulty, or complexity of the lift, toxicity of the product being lifted, and other considerations at the discretion of the producer of the lift plan. Critical lifts require individual lift plans.

General lifts: Are lifts that are neither critical lifts or production lifts. These lifts need not be listed. Example of a general lift is offloading materials from a trailer.

Production lifts: Production lifts are repetitive and do not fall into the classification of a critical lift. Production lifts may all be covered by one lift plan that outlines the parameters and the equipment to be utilized in the lifts as well as the procedures associated with the lift. Example of a production lift is steel erection.

MOBILE CRANE TYPES

Commercial truck mounted crane: A crane consisting of a rotating superstructure (center post or turntable), boom, operating machinery, and one or more operator's stations mounted on a frame attached to a commercial truck chassis, usually retaining a payload hauling capability whose power source usually powers the crane. Its function is to lift, lower, and swing loads at various radii (see Figs. 5-0.2.1-1 and 5-0.2.1-2).

Crawler crane: A crane consisting of a rotating superstructure with a power plant, operating machinery, and boom, mounted on a base and equipped with crawler treads for travel. Its function is to lift, lower, and swing loads at various radii (see Figs. 5-0.2.1-3 and 5-0.2.1-4).

Locomotive crane: A crane consisting of a rotating superstructure with a power plant, operating machinery, and boom, mounted on a base or car equipped for travel on a railroad track. This type of crane may be self-propelled or propelled by an outside source. Its function is to lift, lower, and swing loads at various radii (see Fig. 5-0.2.1-5).

Wheel-mounted crane (multiple control stations): A crane consisting of a rotating superstructure, operating machinery, and operator's station and boom, mounted on a crane carrier equipped with axles and rubber-tired wheels for travel, a power source(s), and having separate stations for driving and operating. Its function is to lift, lower, and swing loads at various radii (see Figs. 5-0.2.1-6 and 5-0.2.1-7).

Wheel-mounted crane (single control stations): A crane consisting of a rotating superstructure, operating machinery, and boom, mounted on a crane carrier equipped with axles and rubber-tired wheels for travel, a power source, and having a single control station for driving and operating. Its function is to lift, lower, and swing loads at various radii (see Figs. 5-0.2.1-8 through 5-0.2.1-10).

MOBILE CRANE GLOSSARY

Accessory: A secondary part or assembly of parts that contributes to the overall function and usefulness of a machine.

Administrative or Regulatory Authority: A governmental agency or the employer in the absence of governmental jurisdiction.

American National Standards Institute (ANSI): Provides the accrediting methodology for development of ASME standards among others.

Angle indicator (boom): An accessory that measures the angle of the boom to the horizontal.

Anti-two-block device: A device that, when activated, disengages all crane functions whose movement can cause two-blocking.

Auxiliary hoist: A secondary hoist rope system used either in conjunction with, or independently of, the main hoist system.

Axis of rotation: The vertical axis around which the crane superstructure rotates.

Axle: The shaft or spindle with which or about which a type of axle assembly including housings, gearing, differential, bearings, and mounting appurtenances.

Axle (bogie): Two or more axles mounted in tandem in a frame so as to divide the load between the axles and permit vertical oscillation of the wheels.

Ballast: Weight used to supplement the weight of the machine in providing stability for lifting working loads (the term *ballast* is normally associated with locomotive cranes).

Base (mounting): The traveling base on which the rotating superstructure of a locomotive or crawler crane is mounted.

Boom (crane): A member hinged to the rotating superstructure and used for supporting the hoisting tackle.

Boom angle: The angle above or below horizontal of the longitudinal axis of the base boom section.

Boom hoist mechanism: Means for supporting the boom and controlling the boom angle.

Boom point: The outer extremity of the crane boom, containing the hoist sheave assembly.

Boom point sheave assembly: An assembly of sheaves and pin built as an integral part of the boom point.

Boom stop: A device used to limit the angle of the boom at the highest recommended position.

Brake: A device used for retarding or stopping motion.

Cab: A housing that covers the rotating superstructure machinery or the operator’s or driver’s station.

Clutch: A means for engagement or disengagement of power.

Commercial truck vehicle: A commercial motor vehicle designed primarily for the transportation of property in connection with business and industry.

Counterweight: Weight used to supplement the weight of the machine in providing stability for lifting working loads.

Crane carrier: The undercarriage of a wheel-mounted crane specifically designed for transporting the rotating crane superstructure. It may or may not provide its own travel mechanism. It is distinguished from a commercial truck vehicle in that it is not designed to transport personnel, materials, or equipment other than the crane rotating superstructure.

Critical lift: A hoisting or lifting operation that has been determined to present an increased level of risk beyond normal lifting activities. For example, increased risk may relate to personnel injury, damage to property, interruption of plant production, delays in schedule, release of hazards to the environment, or other jobsite factors.

Cross-over points: In multiple layer spooling of rope on a drum, those points of rope contact where the rope crosses the preceding rope layer.

Drum: The cylindrical member around which a rope is wound for lifting and lowering the load or boom.

Dynamic (loading): Loads introduced into the machine or its components due to accelerating or decelerating forces.

Ensure: Term used when the meaning "take steps to see that" or "make sure" is intended.

Flange point: A point of contact between rope and drum flange where the rope changes layers.

Gantry (A-frame): A structural frame, extending above the superstructure, to which the boom support ropes are reeved.

Hoist mechanism: A hoist drum and rope reeving system used for lifting and lowering loads.

Jib: An extension attached to the boom point to provide added boom length for lifting specified loads. The jib may be in line with the boom or offset to various angles in the vertical plane of the boom.

Jib backstop: A device that will restrain the jib from turning over backward.

Jobsite: Work area defined by the construction contract.

Load (working): The external load in pounds (kilograms) applied to the crane, including the weight of load attaching equipment such as lower load block, shackles, and slings.

Load block, lower: The assembly of hook or shackle, swivel, sheaves, pins, and frame suspended by the hoisting ropes.

Load block, upper: The assembly of shackle, swivel, sheaves, pins, and frame suspended from the boom point.

Load indicator: A device that measures the weight of the load.

Load ratings: Crane ratings in pounds (kilograms) established by the manufacturer in accordance with Section 5-1.1.

Luffing attachment: A front-end attachment for a mobile crane that uses an upper working boom or jib, which is capable of changing angle during operation and is mounted on top of a lower main boom. This is distinguished from a fixed jib where the operating angle cannot be changed during operation. Typically, the lower boom operating angle can also be changed.

Mast (boom): A frame hinged at or near the boom hinge for use in connection with supporting a boom. The head of the mast is usually supported and raised or lowered by the boom hoist ropes.

Mast (jib): A frame hinged at or near the boom point for use in connection with supporting a jib.

Minimum breaking force: The minimum load at which a new and unused wire rope will break when loaded to destruction in direct tension.

Multiple load line operation: Simultaneous use of two or more lines reeved over sheaves on a single shaft or multiple shafts of a crane with multiple load drums to lift, rotate, or hold a single load.

Normal operating conditions: Conditions during which a crane is performing functions within the manufacturer's operating recommendations. Under these conditions, the operator is at an operator control station described in the instructions for the crane; no other persons, except those designated, are to be on the crane.

Operational aid: An accessory that provides information to facilitate operation of a crane or that takes control of particular functions without action of the operator when a limiting condition is sensed. Examples of such devices include, but are not limited to, the following: anti-two-block device, rated capacity indicator, rated capacity (load) limiter, boom angle or radius indicator, lattice boom hoist disconnect device, boom length indicator, crane level indicator, drum rotation indicator, load indicator, and wind speed indicator.

Outriggers: Extendable or fixed members attached to the mounting base, which rest on supports at the outer ends used to support the crane.

Pawl (dog): A device for positively holding a member against motion in one or more directions.

Payload: The load, or loads, being transported by the commercial truck chassis from place to place.

Pendant: A rope or strand of specified length with fixed end connections.

Power-controlled lowering: A system or device in the power train, other than the load hoist brake, that can control the lowering rate of speed of the load hoist mechanism.

Qualified operator: An operator who has met the requirements of paras. 5-3.1.2(a) through (c).

Qualified person: A person who, by possession of a recognized degree in an applicable field or certificate of professional standing, or who, by extensive knowledge, training, and experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter and work.

Rail clamp: A tong-like metal device mounted on a locomotive crane car, which can be connected to the track.

Rated capacity indicator: A device that automatically monitors radius, load weight, and load rating, and warns the crane operator of an overload condition.

Rated capacity (load) limiter: A device that automatically monitors radius, load weight, and load rating and prevents movements of the crane, which would result in an overload condition.

Reeving: A rope system in which the rope travels around drums and sheaves.

Repetitive pickup point: When operating on a short cycle operation, the rope being used on a single layer and being spooled repetitively over a short portion of the drum.

Rope: Refers to wire rope unless otherwise specified.

Rotation-resistant rope: A wire rope consisting of an inner layer of strand laid in one direction covered by a layer of strand laid in the opposite direction. This has the effect of counteracting torque by reducing the tendency of the finished rope to rotate.

Running rope: A rope that travels around sheaves or drums.

Shall: Term used to indicate that a rule is mandatory and must be followed.

Should: Term used to indicate that a rule is a recommendation, the advisability of which depends on the facts in each situation.

Side loading: A load applied to an angle to the vertical plane of the boom.

Standby crane: A crane that is not in regular service but that is used occasionally or intermittently as required.

Standing (guy) rope: A supporting rope that maintains a constant distance between the points of attachment to the two components connected by the rope.

Structural competence: The ability of the machine and its components to withstand the stresses imposed by applied loads.

Superstructure: The rotating upper frame structure of the machine and the operating machinery mounted thereon.

Swing: Rotation of the superstructure for movement of loads in a horizontal direction about the axis of rotation.

Swing mechanism: The machinery involved in providing rotation of the superstructure.

Swivel: A load-carrying member with thrust bearings to permit rotation under load in a plane perpendicular to the direction of the load.

Swiveling: The rotation of the load attachment portion (hook or shackle) of a load block (lower) or hook assembly about its axis of suspension in relation to the load line(s).

Tackle: An assembly of ropes and sheaves arranged for lifting, lowering, or pulling.

Telescoping boom: Consists of a base boom from which one or more boom sections are telescoped for additional length.

Transit: The moving or transporting of a crane from one jobsite to another.

Travel: The function of the machine moving under its own power from one location to another on a jobsite.

Two-block damage prevention feature: A system that will stall when two-blocking occurs without causing damage to the hoist rope or crane machinery components.

Two-block warning feature: A warning device to alert the operator of an impending two-blocking condition.

Two-blocking: The condition in which the lower load block or hook assembly comes in contact with the upper load block or boom point sheave assembly.

Wheel base: The distance between centers of front and rear axles. For a multiple axle assembly, the axle center for wheel base measurement is taken as the midpoint of the assembly.

Whipline (runner or auxiliary): A secondary rope system usually of lighter load capacity than that provided by the main rope system.

Winch head: A power-driven spool for handling loads by means of friction between fiber or wire rope and the spool.

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