DEVELOPMENT OF A SAFETY MANAGEMENT SYSTEM FOR DRILLING AND SERVICING OPERATIONS WITHIN OSHA JURISDICTION AREA FOR TEXAS

A Thesis

by

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ABSTRACT

Workers of oil and gas extraction industries are exposed to different safety hazards, resulting in fatality rates seven times greater than that of the average U.S. worker. However, oil and gas drilling and servicing operations are only governed by the Occupational Safety and Health Administration (OSHA) General Industry Standards, OSHA Construction Standards, and General Duty Clauses of the Occupational Safety and Health (OSH) Act. Some states have their own regulations regarding the safety of drilling and servicing operations, but Texas, the state with the highest fatality and employment of oil and gas industry, does not have any state regulation.

The objective of the study is to develop a safety management system to improve safety performances of Texas drilling and servicing operations based on OSHA fatal incident data, and the scope of the study is only for the OSHA jurisdiction area for Texas. The study was conducted in two parts. The objective of the first part is to understand current regulations enforced with respect to Texas drilling and servicing operations and determine whether current safety management systems in United States (Process Safety Management, and Safety and Environment Management Systems) can be directly extended to drilling and servicing operations in Texas. The second part of the study, which would be conducted if none of the current management systems are sufficient for extension to drilling and servicing, is to develop a different safety management system specifically for Texas drilling and servicing operations within the OSHA jurisdiction area.

The study evaluated Process Safety Management and Safety and Environment Management Systems and found that developing a new safety management system is a better solution to reduce fatal injuries of Texas drilling and servicing operations, rather than extending the two safety

management systems. In order to develop a new safety management system, causal factors for incidents were identified and categorized to generate safety management elements. The safety management system was developed to integrate both process and personnel safety, containing nine management elements, which are Personal Protective Equipment, Equipment Design/Selection, Inspection and Maintenance, Written Procedure, Hazard Communication, Hazard Assessment, Work Practice, Emergency Response Planning, and Training. The safety management system successfully covers gaps of OSHA General Industry Standards and Construction Standards, and covers frequent violations of the standards. Industries can use the management system as a framework to establish their safety programs.

Future work will include 1) studying effects of human factors on safety performances of drilling and servicing operations, and incorporating human factors into the developed safety management system; 2) consideration of incorporating some management elements, such as auditing, record keeping and incident investigations, into the developed management system; 3) developing metrics to evaluate whether safety programs of industries are effective to comply with the developed safety management system; 4) developing contractor management to provide guidelines for contractor and owner companies and making sure contractors and owners are on the same page regarding safety programs.

DEDICATION

To my father and mother

To my boyfriend, Yibo Zhu

To my friends

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NOMENCLATURE

ANSI	American National Standards Institute
API	American Petroleum Institute
ASEE	American Society of Safety Engineers
AXPC	American Exploration & Production Council
BLS	Bureau of Labor Statistics
BSEE	Bureau of Safety and Environmental Enforcement
CFOI	Census of Fatal Occupational Injuries
CSB	Chemical Safety Board
IADC	International Association of Drilling Contractors
IMIS	Integrated Management Information System
IPAA	Independent Petroleum Association of America
MKOPSC	Mary Kay O'Connor Process Safety Center
OCS	Outer Continental Shelf
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
PSM	Process Safety Management
SEMS	Safety and Environment Management Systems
SIC	Standard Industrial Classification

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1. INTRODUCTION

1.1 Background and Motivation

Average annual occupational fatality rate from 2003 to 2009 in oil and gas extraction industry is seven times higher than the rate for all U.S. workers [1]. Similar to other industries, there are some common safety hazards existing in oil and gas extraction industries, such as falls, struck-by and caught-in/ caught-between. However, oil and gas extraction industries also have some unique hazards including fires, explosions, high pressure equipment, confined spaces and rotating machine hazards, *etc.* [2, 3].

In order to improve safety performances of oil and gas extraction activities, American Petroleum Institute (API), International Association of Drilling Contractors (IADC), and American National Standards Institute/American Society of Safety Engineers (ANSI/ASSE) have published a series of industry practice documents regarding the safety hazards associated with oil and gas extraction activities. Industries are encouraged to follow the practice documents, but are not forced [2]. Currently, federal regulations enforced on oil and gas operations to protect worker's safety are Occupational Safety and Health Administration (OSHA) General Industry Standards, OSHA Construction Standards, and General Duty Clauses of the Occupational Safety and Health (OSH) Act [4]. All aspects of oil and gas well drilling and servicing operations are governed by OSHA General Industry Standards, except for site preparation activities. Site preparation activities, including leveling the site, trenching and excavation, are covered by OSHA Construction Standards. Special hazards existing in workplaces, which are not addressed by either OSHA General Industry Standards and Construction Standards, will be covered by General Duty Clauses [5].

Besides OSHA federal regulations, some states have their own requirements on drilling and servicing operations. These states are California, Alaska, Texas, Utah, and Wyoming [4]. However, among these states, only California and Utah provide state requirements regarding occupational safety. Alaska, Texas, and Wyoming regulate oil and gas industry on licensing or leasing lands for oil and gas exploration and regulate production waste, but there is no regulation regarding occupational safety.

According to the report of Bureau of Labor Statistics [6], from 2007 to 2011, the state with the highest fatal injuries in oil and gas industries is Texas, followed by Oklahoma, Louisiana, New Mexico, and Wyoming. The numbers of fatal injuries during the 5 years and the employment in 2011 are listed in Table 1.

Table 1. Oil and Gas Industry Fatal Injuries [6]

State	Number of Fatal Injuries 2007-2011	Employment in 2011
Texas	199	225,496
Oklahoma	64	49,207
Louisiana	62	48,947
New Mexico	27	16,310
Wyoming	27	16,967

The table indicates that Texas has the highest number of fatal injuries, as well as the highest employment in oil and gas industry. It is possible that fatality rate of Texas is similar to or lower

than the fatality rates of other states. However, given the high number of fatalities, improvement of safety performance in Texas oil and gas industries is still needed. As the state with the highest employment, Texas should be expected to perform better than other states, and reduce the fatalities as much as possible. Currently, Texas drilling and servicing operations are only governed by OSHA General Industry Standards, OSHA Construction Standards, and General Duty Clauses. In order to improve the safety performances of Texas oil and gas drilling and servicing operations, there is an urgent need to evaluate whether current regulations are adequate to address safety hazards associated with these operations, then further study how to reduce fatalities in Texas. Considering the fact that Texas is a coastal state, drilling and servicing operations are conducted both onshore and offshore. Thus, the scope of the study is defined as drilling and servicing operations within the OSHA jurisdiction area for Texas. OSHA has authority onshore and on U.S. navigable waters. For Texas, U.S. navigable waters include inland waters, such as lakes and territorial sea which extends up to 9 nautical miles seaward from the coastline [7].

1.2 Literature Review

In this section, in order to evaluate whether current regulations adequately address safety hazards associated with drilling servicing and operations, OSHA proposed standards specifically for oil and gas well drilling and servicing were reviewed, along with existing management systems which may be extended to drilling and servicing operations. Additionally, previous studies about incidents in oil and gas industries were reviewed to understand their limitations.

1.2.1 OSHA Proposed Standards for Oil and Gas Well Drilling and Servicing

In 1980's, due to the large number of injuries and fatalities in oil and gas well drilling and servicing, OSHA began gathering information to determine whether OSHA General Industry Standards

adequately address the unique safety hazards in these industries. It was determined that the unique safety hazards resulted in high injury and fatality rate, showing OSHA General Industry Standards fail to adequately address these unique hazards. Thus in 1983, OSHA drafted a proposed standard (48 FR 57202) addressing the hazards associated with gas and well drilling and servicing and made it as a supplement to OSHA General Industry Standards [3]. The standards proposed by OSHA provided requirements specifically for drilling and servicing operations such as riding hoisting equipment, operations near overhead power lines, along with requirements for equipment such as derrick and blow out prevention. However, the final action of the proposed standards failed to be executed, and the standard was never enforced. Thus, there continues to be a lack of specific OSHA standard for the oil and gas drilling and servicing industries [8].

1.2.2 Process Safety Management (PSM)

Process Safety Management (PSM) of highly hazardous chemicals was issued by OSHA in 1992 for the purpose of preventing or minimizing the consequences of catastrophic releases of hazardous chemicals. However, PSM does not cover retail facilities, oil or gas well drilling or servicing operations, nor normally unoccupied remote facilities [9]. Oil and gas well drilling and servicing operations were exempted by PSM since OSHA had begun to propose separate rulemaking for drilling and servicing (48 FR 57202). In 2013, in order to improve chemical facility safety and security, OSHA requested comments on a potential revision to PSM and identified seventeen candidate topics for policy changes. One of the candidate topics was to consider whether the PSM exemption on oil and gas well drilling and servicing operations should be removed, since the separate rulemaking (48 FR 57202) failed to be published as a final rule [10].

OSHA has requested comments about whether the PSM exemption on drilling and servicing operations should be removed. Several organizations submitted their suggestions in response to the request. The organizations include the Chemical Safety Board (CSB), the Mary Kay O'Connor Process Safety Center (MKOPSC), the International Association of Drilling Contractors (IADC), as well as the American Exploration & Production Council (AXPC), and the Independent Petroleum Association of America (IPAA).

According to the CSB response to the request for information [11], the CSB suggested PSM that the exemption for oil and gas well drilling and servicing operations should be eliminated and financial analysis of enforcing PSM is necessary to proceed. By reviewing several incidents that the CSB had investigated, they concluded one ubiquitous hazard associated with oil and gas well drilling and servicing operations is hot work activities, typically during maintenance. Since one of PSM elements includes hot work permitting for welding, cutting and brazing, the CSB concluded hazard associated with hot work activities can be controlled effectively by applying PSM on oil and gas drilling and servicing operations.

According to the MKOPSC response [12], it was recommended to evaluate the nature of hazards in drilling and servicing operations before making a decision. Compared to typical process operations, the nature of drilling and servicing operations is different, thus implementing PSM may not yield any benefit. MKOPSC suggested studying process and personnel risk separately. If personnel risk is a major factor in such industries, other solutions can improve safety performances of drilling and servicing operations more effectively than implementing PSM.

Additionally, IADC, AXPC, and IPAA submitted their response and opposed the elimination of the PSM exemption for oil and gas drilling and servicing operations [13, 14]. IADC believes the PSM exemption does little to improve safety, but would make industries impose unnecessary regulatory burdens, since oil and gas well drilling operations pose negligible risk of catastrophic release. Similarly, AXPC and IPAA, representing natural gas and crude oil exploration and production companies, believe PSM is not an effective or efficient way to manage risks associated with oil and gas drilling and servicing operations. Instead, a separate rulemaking is recommended.

Even though different organizations have different suggestions, their suggestions are lack of comprehensive study of incidents. Thus, according to the suggestion provided by MKOPSC, further analysis of incidents happened in oil and gas drilling and servicing operations is needed to understand hazards associated with these operations.

1.2.3 Safety and Environmental Management Systems (SEMS)

The United States has implemented a prescriptive regulatory system for offshore oil and gas industry for many years. After the Macondo blowout happened in 2010, the Bureau of Safety and Environmental Enforcement (BSEE) developed SEMS to prevent the re-occurrence of an incident similar to Macondo blowout and it is the regulatory agency to authorize the enforcement of SEMS [15]. SEMS is a goal-oriented management system designed for offshore operations to improve their safety performances, thus it is only enforced on Outer Continental Shelf (OCS) [15]. OCS means ‘all submerged lands lying seaward and outside of the area of lands beneath navigable waters’ [16].

1.2.4 Previous Studies of Fatal Injuries Related to Drilling and Servicing Operations

In order to draft the separate rulemaking for drilling and servicing operations (48 FR 57202), OSHA conducted three studies about fatal injuries related to the operations in 1980's, based on reports of OSHA fatality/Catastrophe Investigations [3]. The studies were *Selected Occupational Fatalities Related to Oil/Gas Well Drilling Rigs as Found in Reports of OSHA Fatality/Catastrophe Investigations, Selected Occupational Fatalities Related to Oil and Gas Well Drilling and Servicing as Found in Reports of OSHA Fatality/Catastrophe Investigations,* and *Comprehensive Summaries of Serious Accidents in Oil/Gas Well Industry Standard Industrial Classification (SIC)-138* [3]. All of the three studies identified major hazards associated with drilling and servicing operations, and causal factors resulting in incidents. Based on the conclusions from these studies, OSHA proposed the separate rulemaking addressing these hazards.

Recently, there were several studies conducted to analyze fatal incidents related to drilling and servicing operations [1, 17]. Based on a report by Mulloy [1], fatality rates in oil and gas extraction industries are correlated with the number of active rotary rigs, the number of inexperienced workers, and the number of working hours. Also, smaller companies tend to have higher fatality rates. An analysis of different types of fatalities based on the database of Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) found that, from 2003 to 2011, 'transportation incidents are the most frequent, followed by contact with equipment, fires/explosions, exposure to harmful substances/environments, and falls'. On the other hand, Curlee *et al.* conducted a similar study based on OSHA fatality investigations from 1997 to 2003 [17]. The study concluded that major causes of fatalities are struck-by, followed by fires and explosions, and falls. Struck-by events are mainly caused by mechanical, pressure, or falling objects. Further, Curlee *et al.* analyzed incidents by equipment type, well site location, and state.

1.2.5 Limitations of Previous Studies

Even though the previous studies in 1980's revealed detailed facts about fatalities related to drilling servicing and operations, all conclusions of the studies were based on fatalities records from at least 30 years ago. During the past 30 years, operations techniques have advanced, knowledge of both the employee and employer have improved, and the safety culture of the industry has changed. Therefore, the conclusions from these studies may not be very useful for today's oil and gas industries.

As for recent studies, researchers have failed to distinguish between personnel with process safety hazards. Personnel safety hazards affect individuals but cause few effect on processing activities [18]. Examples of personnel safety hazards are falls, electrocutions, struck-by and caught in/between equipment. However, process safety hazards involve loss of containment. For example, fires, explosions, high-pressure shock, and unplanned release of any materials [19]. In Mulloy's report, one of event types was exposure to harmful substances or environments. Exposures to both electricity and harmful substance are included in the event type. Exposure to electricity is personnel hazard, while exposure to harmful substance such as released chemicals is process hazard. On the other hand, according to the study of Curlee *et al*., struck-by event included high-pressure shock. Stuck-by event always refers personnel safety hazard, but high-pressure shock is process safety hazard. Since they failed to distinguish between personnel with process safety hazards, the analysis of event types in these studies could not reveal the nature of fatal incidents related to drilling and servicing operations.

1.3 Problem Statement

As mentioned in the previous section, there are many unique hazards associated with oil and gas drilling and servicing operations. However, there is no specific standard enforced in oil and gas extraction industries. Especially in Texas, where both the employment and fatalities are the highest, there exists neither federal nor state regulations. Even though organizations such as API and IADC provide industry practices, from an industrial standpoint, complying with comprehensive practices is a burden. Instead, a safety management system is preferred to prevent incidents, allowing industries to develop safety programs based on their own safety performances. There is an urgent need to develop a safety management system to improve safety of Texas drilling and servicing operations based on real incident data. Thus, the study

- Analyzed current safety management systems available for other industries in United States and determined if they could be extended to Texas drilling and servicing operations.
- Developed a new safety management system based on incident data, if current safety management systems would not be appropriate for extension to Texas drilling and servicing operations. Since the nature of process incidents and personnel incidents are different, they would be studied separately, but finally the two types of the incidents would be integrated into a single safety management system.

2. METHODOLOGY

The study was conducted in two parts. First, current regulations enforced on drilling and servicing operations would be reviewed and analyzed to determine whether current management systems in United States (*i.e.* PSM and SEMS) could be directly extended to Texas drilling and servicing operations. Since there are several different standards or safety management systems related to drilling and servicing operations, each of them is introduced here briefly. As mentioned earlier, current regulations enforced on drilling and servicing operations are OSHA General Industry Standards, OSHA Construction Standards, and General Duty Clauses of the OSH Act. Unlike OSHA General Industry Standards and Construction Standards, General Duty Clauses are not a list of standards. It only exists to record those hazards which fail to be addressed in either OSHA General Industry Standards or Construction Standards. On the other hand, Construction Standards is only applicable to site preparation, and General Industry Standards fail to address all safety hazards associated with drilling and servicing operations. In another words, current OSHA regulations are not adequate to make drilling and servicing operations safe. Thus, the study focused on understanding the two current management systems in United States (*i.e.* PSM and SEMS) to see whether they could be extended to Texas drilling and servicing operations. Because neither PSM nor SEMS currently is directly applicable for drilling and servicing for Texas, more literature review and data analysis was conducted to evaluate whether the scope of the two management systems could be broadened to Texas drilling and servicing operations within the OSHA jurisdiction. Since none of the current management systems can be extended, the second part of this project is necessary. Specifically, a different safety management system for Texas drilling and servicing operations was developed based on OSHA fatal incident data.

2.1 Data Collection

Fatal incident data from 1992 to 2011 were collected from both OSHA inspection database and OSHA Integrated Management Information System (IMIS) database.

OSHA is authorized to conduct workplace inspections and incident investigations, as well as cite employers if there is any failure to comply with OSHA standards in the workplace. OSHA covers most private sector employers and their workers, excluding self-employed workers, immediate family members of farm employers, and workplace hazards regulated by any other federal agency [20]. OSHA always conducts inspections without advance notices, but for some special circumstances, OSHA will conduct an investigation with a notice and also conduct an accident investigation [21]. A special circumstance, for example, could be a fatal or catastrophic incident (*i.e*. multiple injuries).

All inspection data is stored in OSHA inspection database, including event date, event type, activity ID, injury degree, one-sentence event description, as well as violations of OSHA General Industry Standards and Construction Standards, and cited General Duty Clauses. The inspection data for fatal injuries can be directly downloaded from website. However, investigation summaries for fatalities and catastrophes, which are developed after the inspections, are recorded in OSHA IMIS database. OSHA IMIS database provides complete description of an incident, generally including events leading to the incident and its causal factors [22]. Thus, data was collected from both OSHA inspection database and OSHA IMIS database for the purpose of integrating inspection details and complete descriptions of incidents for further analysis.

OSHA inspection database covers all facilities within the OSHA jurisdiction area. The facilities are categorized to industry groups according to their operations and classified by the Standard Industrial Classification (SIC) code. In order to collect fatal incidents happened during drilling and servicing operations, only the following industries in the group of oil and gas extraction were covered by the study [23]:

1) SIC 1311 Crude Petroleum and Natural Gas

   The operations conducted by the industries include, but are not limited to exploration for crude petroleum and natural gas, drilling/ competing/ equipping wells, and other activities to prepare oil and gas up to the point of shipment from producing property. Both owner and contractor industries operating oil and gas wells are included.

2) SIC 1321 Natural Gas Liquids

   The operations conducted by the industries are primarily producing liquid hydrocarbons from oil and gas fields.

3) SIC 1381 Drilling Oil and Gas Wells

   The industries provide servicing for drilling wells and are only on contract basis. The operations include spudding in, drilling in, re-drilling, and directional drilling.

4) SIC 1389 Oil and Gas Field Services, Not Elsewhere Classified

   The industries are primarily performing oil and gas field service on contract basis, and operations include excavations, cementing wells, swabbing wells and so on.

As mentioned before, OSHA only has authority for onshore and U.S. navigable waters, and only conducts inspections and investigations within its jurisdiction. Thus, only fatal incidents happened in the industries listed above within the OSHA jurisdiction area were covered in the study.

2.2 Analysis of Fatal Incidents

The fatal incident data is from both OSHA inspection data and OSHA IMIS database. Available incident information includes date, event type such as struck-by, fires, and falls, complete descriptions of incidents, violated General Industry Standards, violated General Construction Standards and General Duty Clauses. In order to extract important information of the incidents, following variables were coded:

1. Process Incident/Personnel Incident

   Since the nature of process incidents and personnel incidents are different, the incidents were coded to either process incident or personnel incident according to incident descriptions.

2. Event Type

   Incidents were coded to different types of event, such as fires, explosions, high-pressure shocks/releases, falls, struck-by, *etc*. Even though the OSHA inspection database provides event types of incidents, these event types cannot be divided into personnel incidents and process incidents. For example, high-pressure shock, which is a process incident is reported in the OSHA database as struck-by, which is actually a personnel incident. In order to know subcategories of process incidents and personnel incidents, event types were re-coded according to incident descriptions.

3. Causal Factors

   Causal factors of incidents were coded, in order to study how the fatal incidents and how they can be avoided. Causal factors were identified from three sources:

   - Violated OSHA General Industry Standards and OSHA Construction Standards
   - General Duty Clauses
   - Incident Descriptions

If causal factors of an incident can be identified from violated OSHA General Industry Standards and Construction Standards, it means that OSHA General Industry Standards and Construction Standards have successfully addressed the hazards, but the employer failed to follow the standards and exposed workers to the hazards.

If causal factors of an incident can only be identified from General Duty Clauses or the incident description, it means that OSHA General Industry Standards and Construction Standards do not or not adequately address the hazards. Thus, the gaps of the standards need to be filled.

2.3 Generation of Safety Management Elements

Based on these data analysis of the coded information and literature review, neither PSM nor SEMS was recommended to be extended to drilling and servicing operations. Thus, more analysis was conducted to develop a Safety Management System.

Coded causal factors were categorized to generate candidate safety management elements. In order to explore how deficiency of each candidate management element negatively affects safety performances of the drilling and servicing operations, incidents related to different candidate management elements were studied separately. For each candidate management element, relevant process and personnel incidents were studied separately first, then the findings from both process and personnel incidents were combined to generate an integrated safety management element and determine whether the candidate management element should be included in the safety management system.

3. RESULTS AND DISCUSSIONS

3.1 Can We Extend PSM ?

From 1992 to 2011, there were 349 incidents and 362 fatalities related to drilling and servicing operations within the OSHA jurisdiction area for Texas. Since only 11 out of 349 incidents involved multiple fatalities, each fatality was treated as a single incident in the study. Incidents were grouped into process incidents and personnel incidents. Process incidents included inhalation of any released materials, such as sulfide hydrogen and nitrogen, as well as fires or explosions, and high-pressure shocks. Personnel incidents include electrocutions, falls, struck-by, caught-in or between equipment parts, and other few special circumstances, such as drowning. A comparison between process and personnel incidents and a distribution of different types of incidents are shown in Figure 1 and Figure 2. The two figures show that 77.3% of incidents are personnel incidents, and only 22.7% are process related. There are 14 management elements in PSM and they are specifically designed for process safety. Based on the distribution of process and personnel incidents, PSM may be effective to reduce the 22.7% of incidents. But there are still 77.3% of personnel incidents, which cannot be reduced or avoided by implementing PSM. Thus, to improve the overall safety performances of drilling and servicing operations, simply extending PSM to the operations is not the best solution to control both process and personnel incidents.

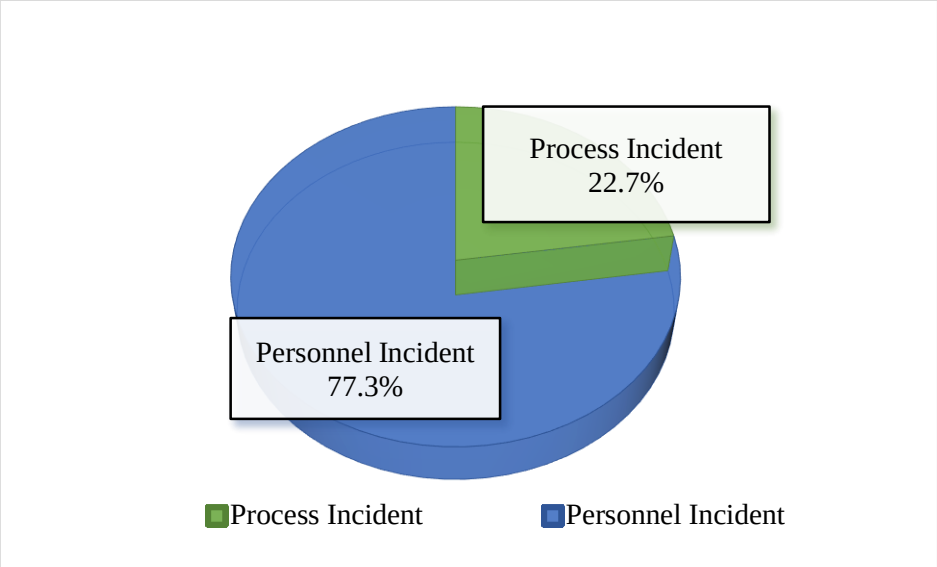

Figure 1. Comparison between Process and Personnel Incidents

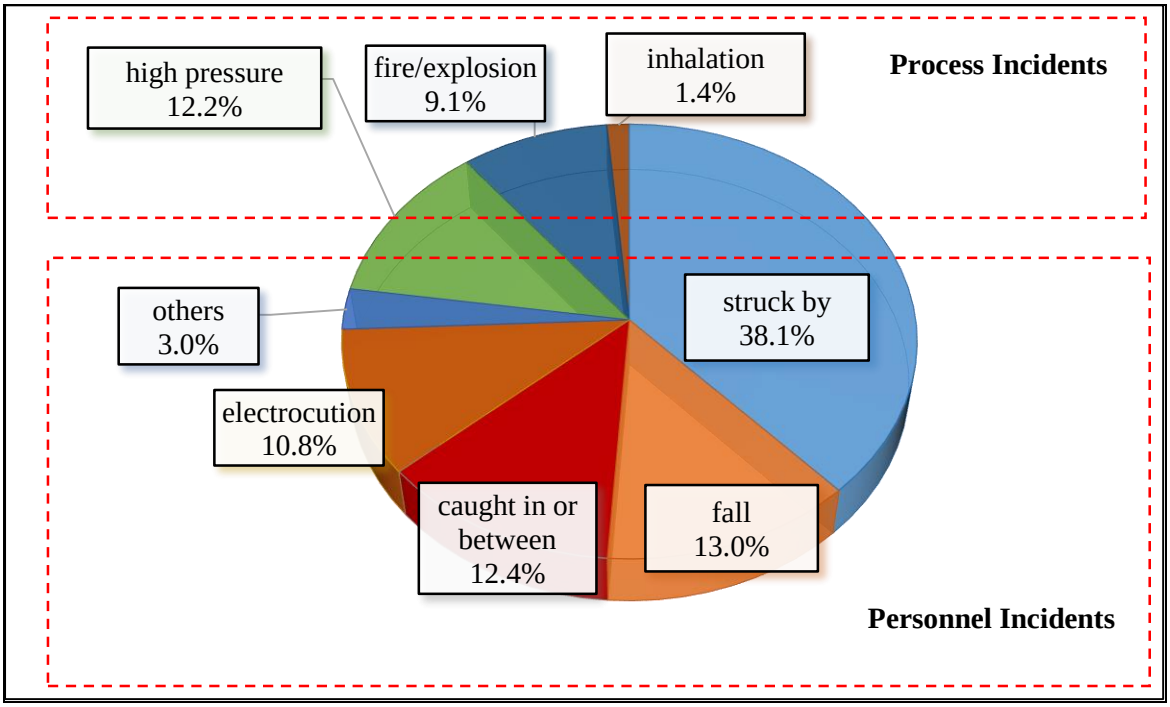

Figure 2. Event Type Distribution for Both Process and Personnel Incidents

3.2 Can We Extend SEMS?

Besides PSM, the other safety management system existing in United States is SEMS, which is enforced on oil and gas facilities on OCS. There are 17 management elements in SEMS, and 13 of them are covered by PSM [24]. One of the goals of SEMS is the prevention of process incidents like Macondo blowout and environmental protection. Thus, compared with personnel safety, process safety are more likely to be focused on by SEMS.

In order to determine whether the scope of SEMS can be broadened to drilling and servicing facilities within the OSHA jurisdiction area for Texas, differences between the OCS facilities and the drilling and servicing facilities within the OSHA the jurisdiction area were studied by literature review. In a study by Mansfield [25], major differences between OCS facilities and the drilling and servicing facilities within the OSHA jurisdiction area were discussed, and the differences were mainly discussed from the aspect of process safety. Compared with drilling and servicing facilities within the OSHA jurisdiction area, OCS facilities face more risks. First, risks for OCS facilities come from the harsh environment. Design requirements for OCS are stricter since the structures are required to respond to extreme sea and wind conditions. Second, OCS facilities are sometimes hundreds of miles away from mainland, thus when an incident happens, it is much harder to reach emergency rescue response to control the consequence of the incident. Lastly, the concentration of flammable vapors can be higher than normal conditions because of the limited layout space of OCS facilities, making fires and explosions more likely to take place. The limited layout space also allows fires and explosions to escalate more rapidly. Mansfield's study is likely to imply that risks in OCS facilities are not comparable with risks of the facilities within the OSHA jurisdiction area.

Simply extending SEMS will not be beneficial to Texas drilling and servicing operations within the OSHA jurisdiction area, either from the aspect of personnel safety or the aspect of process safety. First, similar to PSM, SEMS mainly focuses on process safety, but most incidents related to Texas drilling and servicing operations are personnel incidents. In order to improve the overall safety of drilling and servicing operations within the OSHA jurisdiction area, an integrated safety management system is necessary to control both process and personnel hazards. Second, SEMS is not suitable to prevent process incidents in Texas drilling and servicing operations within the OSHA jurisdiction because it is specifically designed only for OCS facilities. Based on Mansfield's study, risks in OCS facilities are not likely to be comparable with risks of the drilling and servicing facilities within the OSHA jurisdiction area. If extended to the drilling and servicing facilities within the OSHA jurisdiction area to prevent process incidents, SEMS may be overdesigned.

A better solution is to develop an integrated safety management system to address both process and personnel safety hazards, and provide guidelines to prevent people from exposing to the hazards.

3.3 Development of a Safety Management System

Since neither PSM nor SEMS is effectively extended to improve overall safety performances of oil and gas drilling and servicing operations within the OSHA jurisdiction area, an integrated safety management system needs to be developed. However, even though PSM and SEMS are not suitable for the operations, their formats are desirable for developing the new integrated safety management system. Both PSM and SEMS indicate safety management elements that need to be addressed to mitigate risks and there format are practical ones for facility managers and employers

to leverage. For this study, new safety management elements were generated by studying OSHA fatal incident data in order to generate a comprehensive and effective safety management system. The first step was to identify candidate management elements by categorizing causal factors of fatal incidents. Since causal factors are not directly provided in the database, they were identified from three sources: 1) Violated OSHA General Industry Standards and OSHA Construction Standards, 2) General Duty Clauses, and 3) incident descriptions. As mentioned earlier, if causal factors of an incident can be identified from violated OSHA General Industry Standards and Construction Standards, it means that OSHA General Industry Standards and Construction Standards adequately address the hazards, but the incident happened due to the employer's failure to comply with the standards. On the other hand, if causal factors of an incident can only be identified from General Duty Clauses or incident description, it means that OSHA General Industry Standards and Construction Standards do not or not adequately address the hazards. Thus, by categorizing causal factors which were identified from the three sources to generate candidate management elements, the safety management system can be effective since the elements successfully cover the frequent violated OSHA General Industry Standards and Construction Standards, as well as the gaps of OSHA General Industry Standards and Construction Standards. By categorizing causal factors, candidate management elements could be generated. The following examples are selected from fatal incident data to show how causal factors were identified, and how they were categorized to be management elements.

> Example 1: An employee opened the cover of an oil storage tank to gage the amount of water in the tank. He was killed by hydrogen sulfide. OSHA General Industry Standards 1910.134 a (2) was cited for the incident, which requires that a respirator should be provided. Thus one of the causal factors of the incident could be identified as lacking personal protective equipment (PPE). Additionally, according to the incident description,

the incident happened during the operations involving hydrogen sulfide. It could be prevented if there was a sufficient work practice for the operation. Thus, another causal factor could be identified as the deficiency in work practice.

Example 2: An employee worked on the roof of a trailer and fell from the height when he lost balance. He did not wear personnel protective equipment to prevent his fall. No General Industry Standards, Construction Standards, or General Duty Clauses were cited. Thus, the causal factor of the incident only could be identified from the incident description, and was determined as lack of PPE.

Example 3: An employee fell from a stabbing board, wearing a safety harness which was attached to a deceleration lanyard. However, the safety harness was supposed to be secured to an inertia reel or a tail line. No General Industry Standards, Construction Standards or General Duty Clauses were cited. Thus, the causal factor of the incident only could be identified from the incident description and was determined as improper use of PPE.

The causal factors of all of the above example incidents are related to the deficiency in PPE. Thus, the causal factors of these incidents were categorized together, and a candidate management element, which is PPE, was generated.

By identifying and categorizing causal factors of incidents, eleven candidate management elements were generated. They are

(1) Personal protective equipment (PPE): representing the causal factors including improper use of PEE, improper design of PPE or lack of PPE.

(2) Equipment design/selection: representing failure to comply manufacturer's requirements, improper design of equipment, and failure to select appropriate equipment for operations.

(3) Inspection and maintenance: representing lack of routine inspection/maintenance, and poor quality of the routine inspection/maintenance.

(4) Written procedure: representing lack of written procedure, failure to follow written procedure, lack of visual inspection prior to operation, and not clearing people from working areas prior to operations.

(5) Hazard assessment: representing inadequate hazard assessment/job safety analysis, and lack of safety device or engineering control to prevent hazards.

(6) Work practice: representing lack of work practice for lockout, hot work, confined spaces, and operations near power lines.

(7) Training: lack of or inadequate training for employees.

(8) Hazard communication: lack of safety instruction or warning sign, lack of signalman to supervise the operations, and insufficient communication between coworkers.

(9) Emergency response planning: failures to access emergency exit and improper emergency rescue resulting in second-injury.

(10) Environment: extreme weather, for example, rain, strong wind and lightening.

(11) Others: representing causal factors which are failed to be grouped into any other candidate management element.

Since incident information provided by OSHA database is limited, without providing investigation reports for incident, causal factors for some incidents could not be identified from including incident descriptions, violated OSHA General Industry Standards, violated Construction

Standards or General Duty Clauses. Thus, the following analysis is only based on 288 incidents, whose causal factors are identifiable.

Table 2 shows that, 72% of the candidate management elements were identified from OSHA General Duty Clauses and incident descriptions, and only 28% of them were identified from OSHA General Industry Standards and Construction Standards. This indicates that General Industry Standards and Construction Standards do not or inadequately address the hazards to prevent incidents caused by these candidate management elements. If General Industry Standards and Construction Standards could adequately address the hazards, it would be expected that at least 90% of the frequencies of candidate management elements could be identified from General Industry Standards and Construction Standards.

Table 2. Percentage of Causal Factors from Different Sources

Sources	Percentage of Causal Factors
OSHA General Industry Standards and Construction Standards	28%
General Duty Clauses and Incident Descriptions	72%

Figure 3 lists the candidate management elements which were identified and compares those from violated OSHA General Industry Standards and Construction Standards (grey bars) and the frequencies of those which were identified from incident descriptions or General Duty Clauses

(orange bars). Since a single incident can be caused by multiple causal factors, sum of frequencies is not equal to total number of incidents.

Figure 3 more specifically shows the sources for different types of causal factors. For hazard assessment, written procedure, inspection and maintenance, and PPE, frequencies of the elements identified from General Duty Clauses and incident descriptions are much higher than the frequencies of those elements identified from General Industry Standards and Construction Standards. In the best case, 50% of deficiencies in training would be identified from General Duty Clauses and descriptions, and the other 50% would be from General Industry Standards and Construction Standards. If General Industry Standards and Construction Standards could adequately address the hazards, it would be expected that the grey bars would be much taller than the orange bars, and orange bars should be much lower. Thus, based on these results, OSHA General Industry Standards and Construction Standards have gaps to be filled and they are not effective enough to prevent incidents related to drilling and servicing operations. On the other hand, the grey bars indicates that, even though related OSHA General Industry Standards and Construction Standards were in place, incidents still happened due to the failures to comply with the standards. This feature supports the notices that a safety management system is needed to cover the frequent violated OSHA standards as well as fill the gaps of the OSHA General Industry Standards and Construction Standards.

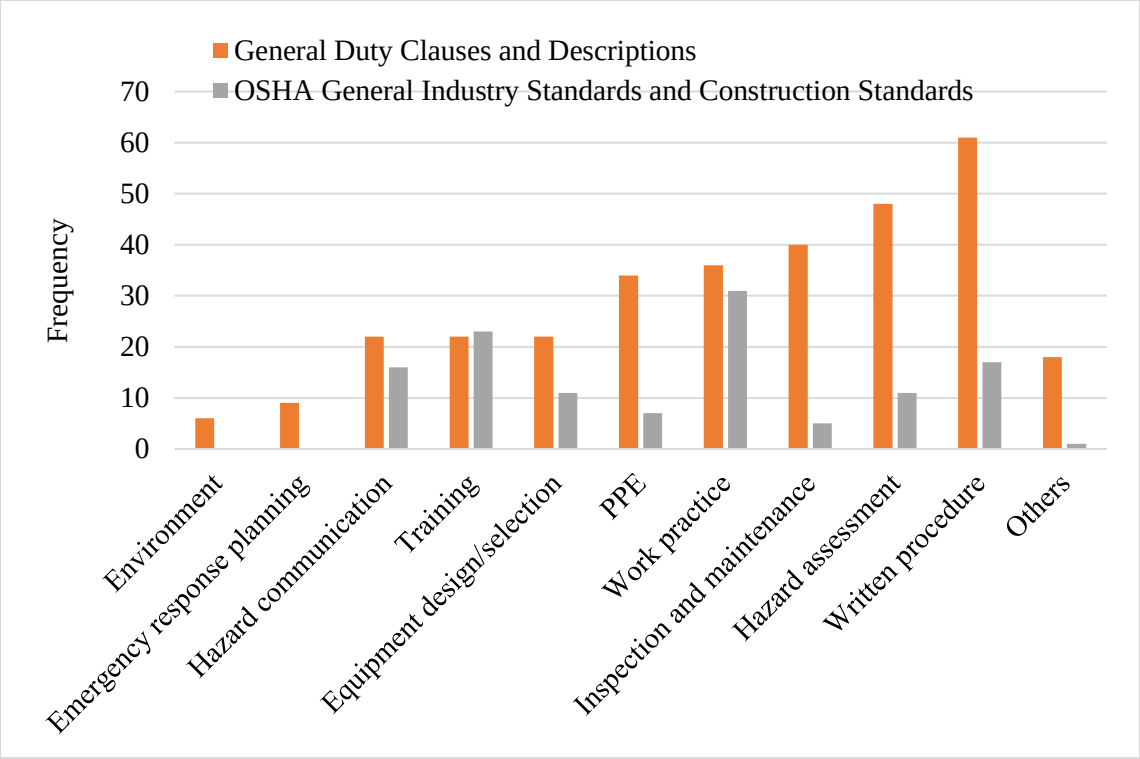

Figure 3. Frequency of Candidate Management Element Identified by Different Sources

Figure 4 shows how different candidate management elements contribute to process and personnel incidents. Among the 288 incidents whose candidate management elements are identifiable, there are 68 process incidents and 220 personnel incidents. The figure shows the percentages of process incidents caused by different candidate management elements, as well as the percentages of personnel incidents caused by different candidate management elements. Since an incident can be caused by multiple candidate management elements, the sum of percentages for either process incidents or personnel incidents may not equal to 100%.

Figure 4 shows that all candidate management elements, except ‘others’, have contributions to both personnel incidents and process incidents, thus, an integrated safety management system

should be developed to control both process and personnel incidents. The management elements are not equally related to both types of incidents. Emergency response planning, hazard communication, work practice, hazard assessment and environment are more important for controlling process incidents than controlling personnel incidents. Written procedure is almost equally important to control both process and personnel incidents. As for other elements, they are more helpful to reduce personnel incidents.

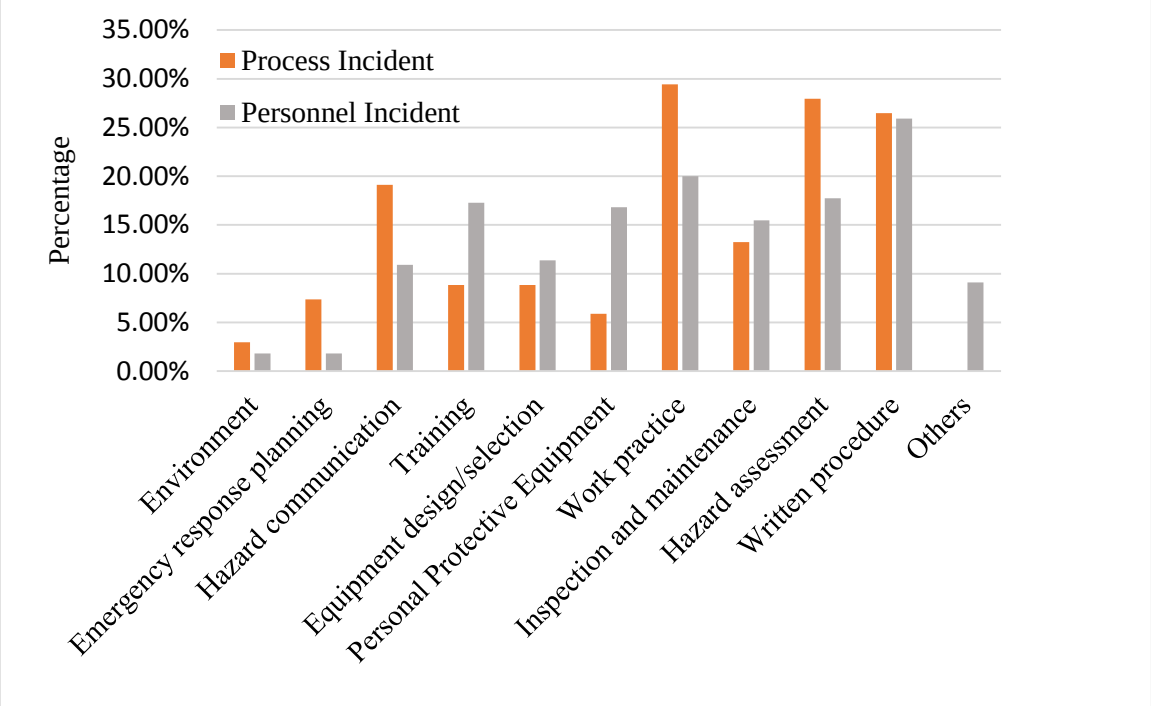

Figure 4. Percentages of Process and Personnel Incidents Caused by Different Candidate Management Elements

In order to develop an integrated safety management system, candidate management elements were studied separately. Each element was studied from the aspects of both process and personnel incidents. Similar incidents were grouped together to summarize important aspects of each element.

Then recommendations for each candidate management element were provided by integrating the studies of process and personnel incidents.

3.3.1 Personal Protective Equipment (PPE)

Appropriate PPE is effective to protect employees when they are exposed to hazards during their tasks. Most common PPE existing in workplaces are safety goggles, face shields, helmets, respiratory devices and protective clothing.

According to Figure 4, 16.82% of personnel incidents and 5.88% of process incidents that happened from 1992 to 2011 were caused by deficiency in PPE. The data is also shown in Table 3.

Table 3. Percentage of Personnel/Process Incidents Caused by Deficiency in PPE

	PPE
Personnel Incidents	16.82%
Process Incidents	5.88%

Out of the personnel incidents, similar incidents were grouped together to be subcategories of incidents. Table 4 shows the subcategories and corresponding percentages.

Table 4. Subcategories of Deficiency in PPE of Personnel Incidents

Subcategories of Deficiency in PPE	Percentage
Lack of PPE	48.65%
Not tying off fall protection equipment	29.73%
Improper use of PPE	10.81%
Inadequate capacity of PPE	8.11%
Poor condition of PPE	2.70%

In order to explore details regarding the incidents, Figure 5 shows distribution of event types caused by lack of PPE. In the figure, the event type ‘others’ only includes drowning.

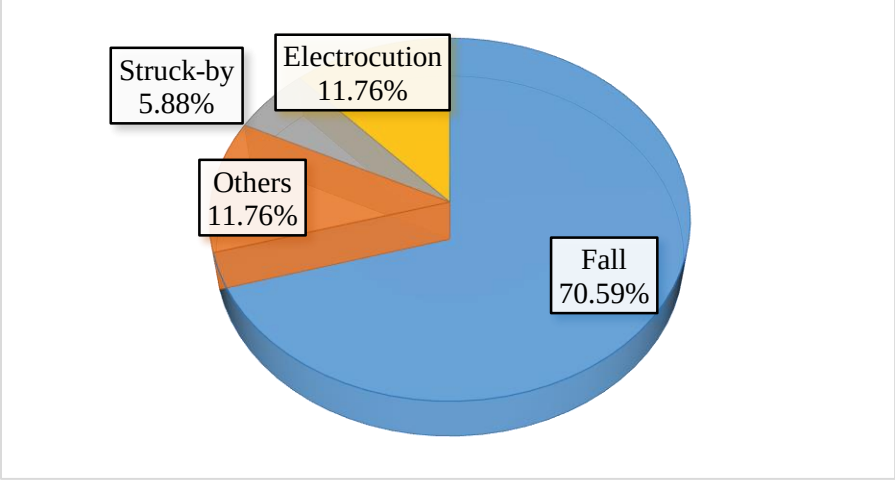

Figure 5. Distribution of Personnel Incident Event Types Related to Lack of PPE

As the above results shown, 48.65% of the personnel incidents occurred because no PPE was used during operations. Lack of PPE resulted in fatalities related to fall hazard most often, followed by electrocution, drowning, and struck-by. In order to reduce the fall hazard, employers need to provide fall protection equipment for employees and take measures to ensure employees wear their PPE while working on heights. Additionally, in order to reduce electrocution hazard, insulated gloves should be used when workers replace electrical fixtures or repair damaged circuits. Considering some drilling and servicing operations are carried out on state waters, employers should provide appropriate PPE, such as life jackets, to prevent drowning hazards and require employees to wear the PPE when necessary. Head protection equipment, such as helmets, is necessary to protect employees from being struck by fallen objects. 29.73% of personnel incidents were fall incidents and were caused when employees did wear PPE but did not tie off their PPE. The situations tended to happen especially when an employee restarted his task after a short rest or other interruptions. Employers are responsible for ensuring that those employees who work on heights wear their PPE all the time. Measures, such as supervision and checklists, could be taken to remind employees to tie off their PPE.

Another major group of the personnel incidents were caused by using PPE improperly, which accounted for 10.81% of the personnel incidents related to PPE. Employers are responsible for ensuring employees understand the proper way to use PPE. Some drilling and servicing operations may involve rotating machines. Securing lanyards at improper positions may cause the lanyards to be entangled in rotating machines and cause people to be caught between machines.

Additionally, 8.11% of the personnel incidents happened because of inadequate capacity of PPE, when falling objects broke through head protections and killed employees. Considering that metal

and heavy equipment/assemblies can fall from heights during drilling and servicing operations, head protection equipment used in other industries may not effectively protect workers in oil and gas industries. Thus, head protection equipment for drilling and servicing operations is recommended to be selected or upgraded according to the conditions of the operations.

Last but not least, 2.70% of the personnel incidents were electrocution since employees wore wet gloves during the maintenance of electrical equipment. These similar incidents could be avoided if the employee was able to identify whether PPE was in a reliable condition to use. Thus employers are responsible for ensuring that their employees are able to evaluate the reliable conditions of PPE.

On the other hand, as for the process incidents which accounted for 9.76% of the incidents related to PPE, all the incidents were caused because there was lack of respiratory equipment. Employees were exposed to the releases of nitrogen and hydrogen sulfide. Thus, employers should provide respirators and make sure employees wear appropriate PPE such as respirators when there is a possible exposure to asphyxiation hazard.

According to the results and discussions above, PPE is an important component of safety management system, especially for preventing personnel incidents of drilling and servicing operations.

Regarding PPE, employers should make sure that:

- Possible hazards existing in workplaces are recognized and appropriate PPE for workers is provided according to the hazards the employees may be exposed to.

- PPE should be provided to protect workers from, but not limited to, fall, struck-by, electrocution, inhalation, and drowning hazards.
- PPE should be of safe design for drilling and servicing operations to be performed.
- Employers need to make employees at least understand the followings by providing instruction manuals, checklists, or supervision.
    - when PPE is necessary to wear
    - what PPE is necessary to wear
    - whether PPE is in a reliable condition
    - proper manners to use PPE, for example, securing lanyard at a proper position and tying off fall protection equipment all the time

3.3.2 Equipment Design/Selection

According to Figure 4, 11.36% of personnel incidents and 8.82% of process incidents that happened from 1992 to 2011 were caused by improper equipment designs or equipment selections. The data is also shown in Table 5.

Table 5. Percentage of Personnel/Process Incidents Caused by Deficiency in Equipment Design/Selection

	Equipment Design/Selection
Personnel Incidents	11.36%
Process Incidents	8.82%

Personnel incidents were grouped to subcategories. The subcategories and corresponding percentages are shown in Table 6.

Table 6. Subcategories of Deficiency in Equipment Design/Selection of Personnel Incidents

Subcategories of Deficiency in Equipment Design/Selection	Percentage
Improper design of walking surfaces	26.92%
Improper design of wiring or electrical equipment	26.92%
Improper equipment for loading/lifting operations	15.38%
Not complying with manufacturer's requirements	15.38%
Miscellaneous	15.38%

26.92% of the personnel incidents could be prevented if there were better designs of walking surfaces. Employees need to conduct drilling and servicing operations on derricks. In order to prevent or reduce falls from the derricks, walking or working surfaces should have enough structural integrity to support employees, and should have ample spaces for working to avoid accidentally hitting any equipment or machine. Floor openings should be guarded with handrails as required by OSHA General Industry Standards 1910.23. The set of standards was cited frequently according to investigation records, but could be helpful to prevent fall incidents. Another 26.92% of the personnel incidents were electrocution, because of deficiencies in wirings or electrical equipment designs. The deficiencies included the following situations:

- Fuses protecting the circuit were rated higher than permitted circuits
- Grounding paths were not continuous and effective

- Open conductors did not comply with the minimum clearances from the ground as OSHA required
- Electrical equipment was not installed and used in accordance with instructions
- A cord set did not have a grounding blade on its attachment plug

In order to prevent the deficiencies in wirings and electrical equipment designs, employers should be responsible for ensuring that the designs comply with manufacturer's requirements and relevant OSHA regulations, as well as, making sure installations are completed by qualified technicians.

Besides, 15.38% of the personnel incidents happened because equipment did not have enough capacity for loading and lifting operations. These improper equipment resulted in falls of loaded or lifted parts and exposed employees to struck-by and caught-in/between hazards. Additionally, failures of complying with manufacturer's requirements accounted for another 15.38% of the personnel incidents, including using parts or assemblies which did not comply with manufacturing specifications, and not substituting parts or assemblies with manufacturer approved replacements.

Other miscellaneous incidents are related to deficiencies in equipment designs or selections, but are failed to be categorized to any other subcategory. The miscellaneous incidents indicate that

- A truck should be equipped with a back-up alarm to warning surrounding employees
- Tong safety lines and snub lines should be sufficiently short to prevent more than a one-quarter rotation of tongs
- The configuration of knobs should be designed properly so that operators can easily distinguish between different ones

All process incidents related to the deficiency in equipment design/selection were caused by improper pipe design. The incidents indicate that employers should at least ensure all pipe fittings/valves/unions comply with manufacturer's specifications, and ensure pipe fittings/valves/unions have working pressure ratings equal to or greater than maximum anticipated pressures.

As the above results shown, improper equipment design and improper equipment selected for operations can result in both personnel and process incidents. However, these incidents can be prevented by making improvements on equipment design/selection during the initial stage of operations. In order to reduce these preventable incidents, equipment design/selection should be one of the management elements in the safety management system.

Regarding equipment design/selection, employers should be responsible for:

- Installing equipment following manufacturer's requirements
- Modifying/replacing equipment with manufacturer's approvals
- Designing or selecting appropriate equipment to make sure the equipment has proper capability to handle all possible operation conditions
- Following relevant OSHA General Industry Standards to design equipment since the standards provides detailed requirements, especially for the design of walking or working surfaces in 1910.23, and the design of wiring and electrical equipment in 1910.303, 1910.304 and 1910.305.

3.3.3 Inspection and Maintenance

According to Figure 4, 15.45% of personnel incidents and 13.24% of process incidents that happened from 1992 to 2011 were caused by the lack of inspection and maintenance, or poor quality of maintenance. The data is also shown in Table 7.

Table 7. Percentage of Personnel/Process Incidents Caused by Deficiency in Inspection and Maintenance

	Inspection and Maintenance
Personnel Incidents	15.45%
Process Incidents	13.24%

Regarding personnel incidents, Figure 6 shows the detailed subcategories of the personnel incidents.

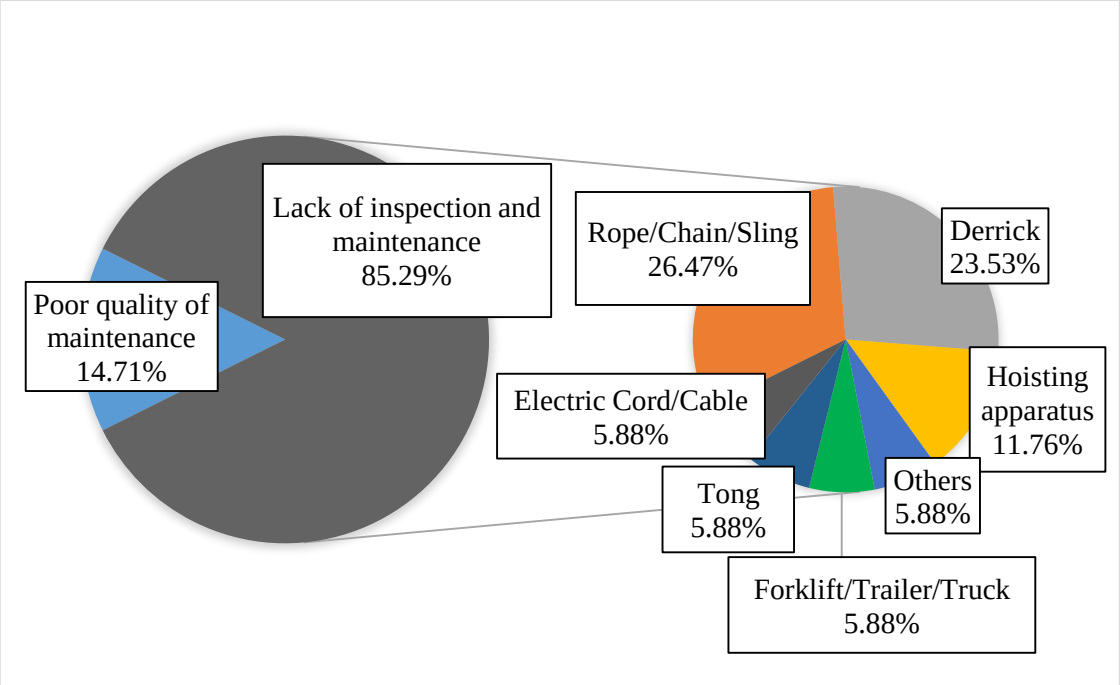

Figure 6. Details of Personnel Incidents Caused by Deficiency in Inspection and Maintenance

Figure 6 shows that 85.29% of the personnel incidents were caused by defective equipment which lacked inspection or maintenance. For the rest of the personnel incidents which accounted for 14.71%, employees found that equipment was defective and performed maintenance, however, maintenance was in poor quality and did not repair the equipment to a safe condition. Thus employers should improve the maintenance quality and ensure defective equipment is removed from service. Regarding the equipment lacking of sufficient inspection and maintenance, top equipment was ropes/chains/slings, followed by derricks, hoisting apparatus such as elevators and travel blocks, forklifts/trailers/trucks, tongs, and cords/cables. Others represent miscellaneous equipment, such as defective ladders and clutches. When conducting drilling and servicing operations, ropes/chains/slings are important equipment for rigging up/down, hoisting heavy attachments and connecting counterweights. Failures of the equipment could lead to struck-by or

caught-in/between events. The equipment should be inspected frequently. Additionally, employers should inspect structural integrities of derricks to prevent or reduce incidents caused by derrick collapses. A derrick and its auxiliary parts should be maintained in a safe condition. Routine inspection and maintenance should be conducted at least for hoisting apparatus, forklifts/trailers/trucks, and tongs to prevent struck-by and caught-in/between incidents. Electrical cords and cables should be inspected to prevent electrocution.

On the other hand, subcategories of process incidents caused by deficiency in inspection and maintenance are shown in Table 8.

Table 8. Subcategories of Deficiency in Inspection and Maintenance of Process Incidents

Subcategories of Deficiency in Inspection and Maintenance	Percentage
Failure of high pressure pipes during normal operations	77.78%
Unqualified employees conducting maintenance	11.11%
Lack of/Insufficient safety inspection program for vacuum tank trucks	11.11%

As shown in Table 8, 77.78% of the personnel incidents were caused by the failures of high pressure pipes during normal operations. High pressure pipes should be inspected and maintained to ensure the integrity of pipe threads and pipe fitting threads, and ensure nipples and valves on high pressure pipes are in reliable and operable conditions, without any corrosion. Additionally, 11.11% of incidents indicate that when a high pressure pipe or a hose requires maintenance, only a qualified technician should be assigned for the maintenance. Otherwise, an unqualified

technician may be struck by a high pressure pipe because of an improper operation. Another 11.11% of incidents indicate that a systematic safety inspection program for vacuum tank trucks should be developed to avoid the explosions caused by overpressure.

Regarding the drilling and servicing operations, deficiency in inspection and maintenance is one of major causal factors leading to fatal incidents and should be one of the safety management elements. The management element is similar to the Mechanical Integrity of OSHA PSM. However, for drilling and servicing operation, the management element is effective to prevent or reduce both process and personnel incidents.

According to the study, employers are responsible for developing an inspection and maintenance program to ensure equipment is maintained in a reliable and safe condition. The program should at least address that:

- Critical equipment should be inspected routinely, for example, ropes, chains, slings, derricks, forklifts, trailers, trucks, hoisting equipment, tongs, and pipes.
- Employers should clarify frequencies of routine inspections.
- Employers should maintain records of inspection and maintenance.
- Inspection and maintenance should be conducted by qualified technicians.
- Defective equipment which may expose an employee to injury or fatality should be removed from service and cannot be used until it is maintained to a safe condition. If the equipment is necessary for an immediate operation, occasional maintenance is acceptable, but employers should ensure that equipment is safe to use during the operation and maintain the equipment immediately after the operation.

3.3.4 Written Procedure

According to Figure 4, 25.91% of personnel incidents and 26.47% of process incidents happened due to the deficiency in written procedure. The data is also shown in Table 9.

Table 9. Percentage of Personnel/Process Incidents Caused by Deficiency in Written Procedure

	Written Procedure
Personnel Incidents	25.91%
Process Incidents	26.47%

Regarding personnel incidents, subcategories of the incidents caused by deficiency in written procedure are shown in Table 10.

Table 10. Subcategories of Deficiency in Written Procedure of Personnel Incidents

Subcategories of Deficiency in Written Procedure	Percentage
Lack of/Insufficient written procedure of loading/hoisting operations	49.12%
Lack of/Insufficient visual inspection before an operation	15.79%
Unqualified people and unclear responsibilities	12.28%
Lack of/Insufficient written procedure of tong operations	8.77%
Lack of/Insufficient written procedure of oil field activities involving reseating/removing horse heads	3.51%
Miscellaneous	10.53%

49.12% of the personnel incidents caused since written procedure of loading/hoisting operations was lacking or insufficient. Based on the study of the incidents caused by the deficiency in the candidate management element, written procedure of these operations should be provided and at least address that loads and hosting attachments are safely secured and employees should be cleared away from the working areas. Also, critical components of hoisting equipment should be visually inspected before operations. 15.79% of the incidents were caused by lack of visual inspections before rig operations and operations near electrical equipment. Even though routine inspections should be conducted by employers to ensure the safe conditions of the working environment, employers should require employees to conduct visual inspections prior to operations in case there are some damages or defects that happened before the next routine inspection. Before any rig operation such as rigging up, rigging down or leveling a rig, employees should visually inspect the derrick and its auxiliary parts, and ensure the parts which easily fall from the derrick are secured to safe positions. Thus, written procedure of rigging up/down and leveling a rig should at least addresses the inspection of the derrick before the operation. Similarly, before conducting operations involving electrical equipment, as OSHA General Industry Standards 1910.334 requires, portable cord and plug connected equipment and flexible cord sets should be visually inspected before the use on any shift for defects and damages.

Besides, 12.28% of the personnel incidents happened since employers failed to assign qualified people to conduct operations and failed to clarify employees' responsibilities. The incidents were especially likely to happen when employees were handling heavy materials; for example, when employees moving drilling stems/drilling rigs and loading heavy equipment on trailers. Thus, written procedure should be in place, assigning enough qualified employees to cooperate in operations, clarifying their responsibilities and providing employees safe working orders. 8.77%

of the incidents happened during tong operations indicate that written procedure of tong operations should be in place, at least addressing clearing people away from tongs. Few incidents accounting for 3.51% indicated that employers should provide written procedure of oil field activities involving reseating or removing horse heads. 10.53% of the personnel incidents could not be categorized to any other category, but indicate written procedures should be in place for rigging up doghouse, spinning chain operations, and jarring operations.

Subcategories of process incidents are shown in Table 11.

Table 11. Subcategories of Deficiency in Written Procedure of Process Incidents

Subcategories of Deficiency in Written Procedure	Percentage
Lack of/Insufficient written procedure for activities involving high pressure pipes or equipment	88.89%
Lack of/Insufficient written procedure for excavation	11.11%

According to Table 11, 88.89% of the process incidents involved high pressure shocks/releases. In order to reduce and prevent incidents of high pressure shocks/releases, written procedure for operations involving high pressure equipment should be provided, at least addressing that:

- Specifications such as maximum working pressure should be checked before operations, to prevent from exceeding the yield strength.
- Inspection of high pressure equipment prior to operations should be conducted to ensure pressurized lines or hoses are secured safely, and ensure relief valves are in good conditions.

- Inspection of high pressure equipment should be conducted to confirm whether the equipment is unpressurized, if necessary.
- People should be cleared away from the dangerous working areas.

The rest of the process incidents were fires, accounting for 11.11%, indicating that written procedure for excavation is needed. Locations of utility installations should be determined during excavations to make sure further drillings will not hit utility lines and make gas release.

Employers should provide written procedure to instruct employees to safely conduct activities involved in drilling and servicing operations, and take written procedure into account when establishing their safety programs. Employers should develop written procedures at least addressing:

- Tong operations
- Loading/hoisting operations
- Rigging up/down and leveling a rig
- Excavations
- Activities involving the removing or reseating of horse heads
- Activities involving high pressure pipelines and equipment
- Visual inspections to be conducted prior to operations
- Responsibility of each employee involved in activities

3.3.5 Hazard Assessment

Hazard assessment is a critical component of the safety management elements for both process and personnel safety. For personnel safety, it also refers to job safety analysis. Before a process or a task starts, hazard assessment is necessary to identify potential hazards and take preventive

measures to protect employees from being exposed. Preventive measures include installing safety devices and implementing proper engineering controls.

According to Figure 4, 17.73% of personnel incidents and 27.94% of process incidents happened because hazard assessment was lacking or inadequate. The data is also shown in Table 12.

Table 12. Percentage of Personnel/Process Incidents Caused by Deficiency in Hazard Assessment

	Hazard Assessment
Personnel Incidents	17.73%
Process Incidents	27.94%

Regarding personnel incidents, subcategories of the incidents are shown in Table 13.

Table 13. Subcategories of Deficiency in Hazard Assessment of Personnel Incidents

Subcategories of Deficiency in Hazard Assessment	Percentage
Lack of safety devices to prevent materials from falling or rolling off	48.72%
Inadequate Job Safety Analysis	15.38%
Lack of/Insufficient hazard assessment to prevent electrocution	15.38%
Lack of guarding moving parts	7.69%
Miscellaneous	12.82%

48.72% of the personnel incidents were caused by lack of safety device to prevent materials from falling or rolling off, and 15.38% of the personnel incidents indicating there was inadequate job safety analysis in general. Besides, 15.38% of the incidents were caused by inadequate hazard assessment to prevent electrocution. Incidents caused by lacking guarding of moving parts surrounding pump jacks accounted for 7.69%. Struck-by hazard is one of major hazards associated with drilling and servicing operations. Counterweights, traveling blocks, crown blocks, and lifting attachments are major sources of the incidents when they are failed to be secured with proper safety devices and accidentally fall. Safety devices, such as anti-two blockings and safety latch type hooks, can be used to prevent the hazard. Additionally, tractor trailers and trucks are used frequently to handle tubular materials, and employees are needed to help with loading or unloading. Tractor trailers and trucks should be installed with pipe stops to prevent pipes from rolling off to strike surrounding employees. Before operations, employers are responsible for reviewing entire operations, identifying potential hazards, and installing proper safety devices to secure the tubular equipment to protect employees from struck-by hazard. Besides, employees can also be exposed to struck-by hazard when they work near moving parts. If there is a potential of moving parts striking employees, employers should safely guard the moving parts to prevent employees from accessing to the immediate areas when these moving parts are in operations.

Another existing hazard is electrocution. Employees are exposed to electrocution hazard when energized equipment is not equipped with bonding or grounding, when there is no ground fault circuit protection, or when electrical equipment is not safely guarded. In order to ensure employees can be free from electrocution hazard, employers should effectively identify the hazard and take measures to protect employees. Last but not least, 12.82% of personnel incidents were miscellaneous, but the occurrences of them indicate that hazard assessment is needed to determine

whether it is necessary to wear PPE, whether a ladder should be installed with a safety device, whether a rollover protection device should be installed on a truck, and whether employees are protected from cave-in during excavations. These incidents did not happen frequently and could not be categorized to any other category, but employers should consider these cases when implementing hazard assessment.

Regarding process incidents, subcategories of deficiency in hazard assessment are shown in Table 14.

Table 14. Subcategories of Deficiency in Hazard Assessment of Process Incidents

Subcategories of Deficiency in Hazard Assessment	Percentage
Lack of/Insufficient hazard assessment for pressurized line	47.37%
Lack of/Insufficient hazard assessment for fire/explosion hazard	26.32%
Miscellaneous	26.32%

Hazard assessment is necessary to identify fire and explosion hazard and high-pressure release hazard. 47.37% of the process incidents were caused by high pressure because pressurized lines were not secured or there was no relief valve. In order to prevent employees from deaths by accidental high pressure shocks and whipping hoses, employers should implement hazard assessment to understand the pressure release hazard. Preventive measures include securing pressurized hoses efficiently to avoid employees being hit, and installing appropriate relief valves to prevent overpressure. Combustible and flammable mixtures exist in oil and gas drilling fields. Fumes of the mixtures can be ignited by static electrical discharges and lightening if the mixtures

are improperly transferred and stored. 26.32% of process incidents were fires and explosions that caused by poor grounding or bonding. Bonding and grounding is necessary to prevent fires and explosions. Employers are responsible for assessing whether there is any fire or explosion hazard then install a bonding or a grounding on tanks and vacuum trucks if necessary. There were 26.32% of process incidents could not be categorized to any other category, but they indicate that adequate hazard assessment is important for safety designs, for example, not using fluorescent lights when there is any fire or explosion hazard, protecting valves if it is possible to be hit by kelly hose, and installing check valves in discharge lines from pumping equipment if necessary, and so on.

According to the results and discussions above, employers are responsible for performing hazard assessment before exposing their employees to potential hazards. Employers should at least ensure that:

- Hazard assessment is implemented before any operation or task starts.
- Hazard assessment should be effective and comprehensive to identify all potential hazards.
- Employees should be protected from identified hazards via effective preventive measures.
- Effective preventive measures are not limited to installing safety devices or implementing engineering controls.
    - Safety devices include but are not limited to,
        - means to secure equipment to prevent falling and rolling off
        - means to secure pressurized lines to prevent whippings
        - bonding or grounding
        - safety relieve valves
        - appropriate blow-out prevention devices
    - Engineering controls include but are not limited to,

- guarding energized equipment to prevent contacts
- guarding moving parts by preventing the access to the immediate area surrounding a pump jack

3.3.6 Hazard Communication

According to Figure 4, 10.91% of personnel incidents and 19.12% of process incidents were caused by deficiency in hazard communication. The data is also shown in Table 15.

Table 15. Percentage of Personnel/Process Incidents Caused by Deficiency in Hazard Communication

	Hazard Communication
Personnel Incidents	10.91%
Process Incidents	19.12%

For the personnel incidents caused by hazard communication, subcategories of the incidents are shown in Table 16.

Table 16. Subcategories of Deficiency in Hazard Communication of Personnel Incidents

Subcategories of Deficiency in Hazard Communication	Percentage
Insufficient communication for truck/forklift operations	33.33%
Insufficient communication between coworkers and between workers in different consecutive shifts	25.0%
Insufficient hazard communication for electrocution hazard	20.83%
Insufficient warning of dangerous working zones	16.67%
Hazard communication not understandable	4.17%

As shown in Table 16, 33.33% of the personnel incidents happened during truck or forklift operations. There were two reasons resulting in the incidents. First, there was lack of signalman to guide the operations. Second, signalmen were assigned to the operations, but failed to ensure safe conditions before they signaled, or their messages were misunderstood by operators. For truck and forklift operations, large loading equipment may lead to poor visibility of operators, thus signal men are necessary to be assigned to help with the operations. Also, it is important to make sure operators and signal men remain in constant communications and signaling messages are easily understandable.

25.0% of the personnel incidents were because of insufficient communications between coworkers or between the workers in different consecutive working shifts. During these operations, it is important for coworkers to communicate efficiently, so that a worker will not be exposed to any hazard during tripping in, rigging up/down and/or other various operations. Electrocution accounted for 20.83% of the incidents and was caused since employers failed to inform employees about the hazard. OSHA General Industry Standards 1910.335 (b), which requires alerting

techniques to prevent electrocution hazards, was cited frequently. As the standard requires, electrocution hazards should be informed to employees and appropriate alerting techniques to limit employees' accesses include using safety signs and tags, using barricades in conjunction with signs, and stationing attendants to warn employees. 16.67% of the incidents were caused when employees entered dangerous working areas, such as a loading zone, and a falling zone. Employers should take appropriate measures to inform the hazards associated with these working areas to employees, in order to avoid accidental accesses. The measures include assigning an employee to supervise the dangerous zones to prevent entering, and utilizing barricades or danger tags to indicate the hazards. 4.17% of the incidents indicate that warning postings should be understandable. If necessary, warnings should be delivered bilingually.

Regarding process incidents caused by deficiency in hazard communication, subcategories of the incidents are shown in Table 17.

Table 17. Subcategories of Deficiency in Hazard Communication of Process Incidents

Subcategories of Deficiency in Hazard Communication	Percentage
Lack of/Insufficiently informing hazards	71.43%
Insufficient communication between coworkers	28.57%

71.43% of process incidents indicate that there was a lack of an appropriate method to inform about fire hazard, high-pressure hazard or lacking chemical safety information. When there is any identified hazard, warning system should be used to make other employees recognize the hazard. OSHA General Industry Standards 1910.145 and 1910.1200 were cited frequently. And as these

standards require, safety instruction signs and danger tags should be in place at major hazard situations to indicate identified hazards. Also, considering flammable materials existing in oil and gas industries, safety information of chemicals and relative safety measures should be provided as 1910.1200 requires to prevent employees from being exposed to hazards. Besides, 28.57% of the process incidents were caused because there was a lack of communication between coworkers. For example, tests of blowout preventers were not informed to employees so that employees working near the blowout preventers were killed by high pressure shocks, or an operator fired an explosive charge without a positive signal from the cooperated explosives expert and an explosion occurred. Thus, similar to personnel incidents, communication between coworkers are important to prevent or reduce process incidents.

According to results and discussions above, it can be found that efficient hazard communication is necessary to make sure employers inform potential hazards to employees and protect employees from the hazards. Hazard communication can be delivered by safety signs, barricades, signals, or communications between coworkers. Employers should develop a written hazard communication program, and should at least ensure that:

- Communications between coworkers are efficient. The communications between coworkers are especially necessary
    - For operations involving activations of energized equipment, such as main drums
    - For rigging up or rigging down operations
    - Between the workers in different two consecutive working shifts
- Adequate measures for hazard communication are developed to inform employees about
    - hazards associated with truck/forklift operations
    - hazards in the dangerous working areas such as falling zones and loading zones

- hazards of chemical materials
- electrocution hazard

- Hazard communication is delivered appropriately. Signal words and hazard messages are understandable to all employees who may be exposed to hazards.
- OSHA General Industry Standards which are related with hazard communication should be followed. The standards include 1910.145 which is specifications for accident prevention signs and tags, 1910.335 (b) which is alerting techniques of electrical equipment, as well as 1910.1200 which is hazard communication of hazardous substances

3.3.7 Work Practice

According to Figure 4, 20.0% of personnel incidents and 29.41% of process incidents were caused by deficiency in safe work practice. The data is also shown in Table 18.

Table 18. Percentage of Personnel/Process Incidents Caused by Deficiency in Work Practice

	Work Practice
Personnel Incidents	20.0%
Process Incidents	29.41%

Table 19 shows that the personnel incidents could be prevented by implementing safe work practices for operations near overhead power lines or controlling hazardous energy sources. Deficiency in each of the two work practices accounted for 50.0% of the personnel incidents.

Table 19. Subcategories of Deficiency in Work Practice of Personnel Incidents

Subcategories of Deficiency in Work Practice	Percentage
Lack of/Insufficient work practice for operations near overhead power lines	50.0%
Lack of/Insufficient work practice for control of hazardous energy sources	50.0%

First, one of main causal factors of the personnel incidents was lack of or insufficient work practice for operations near overhead power lines. Forklift and truck operations are common for handling huge equipment, such as derricks and rigs, during drilling and servicing operations. When working near overhead power lines, the vehicles may hit power lines so that employees working on the vehicles can be exposed to electrocution hazard. Safe work practice for the operations near overhead power line is necessary, and employers should make sure that the vehicles have enough clearances with overhead power lines to avoid accidental contacts. Among the incidents that happened near overhead power lines, 72.73% of them resulted in the citations of OSHA General Industry Standards 1910.333, which contains minimum requirements for clearances of those vehicles or mechanical equipment being elevated near energized overhead power lines. When employers implement their safe work practice of operations near overhead power lines, the requirements in OSHA 1910.333 should be used as basic guidelines.

Second, the other main causal factor of personnel incidents was the deficiency in controlling hazardous energy sources. Hazardous energy sources are the sources which can release energy to harm employees, including falling objects, rotating machines, accidental moving of vehicles, energized electrical equipment, and pumping systems. Figure 7 shows the distribution of the

incidents resulted in lack of/insufficient controlling hazardous energy sources by related equipment/ machines.

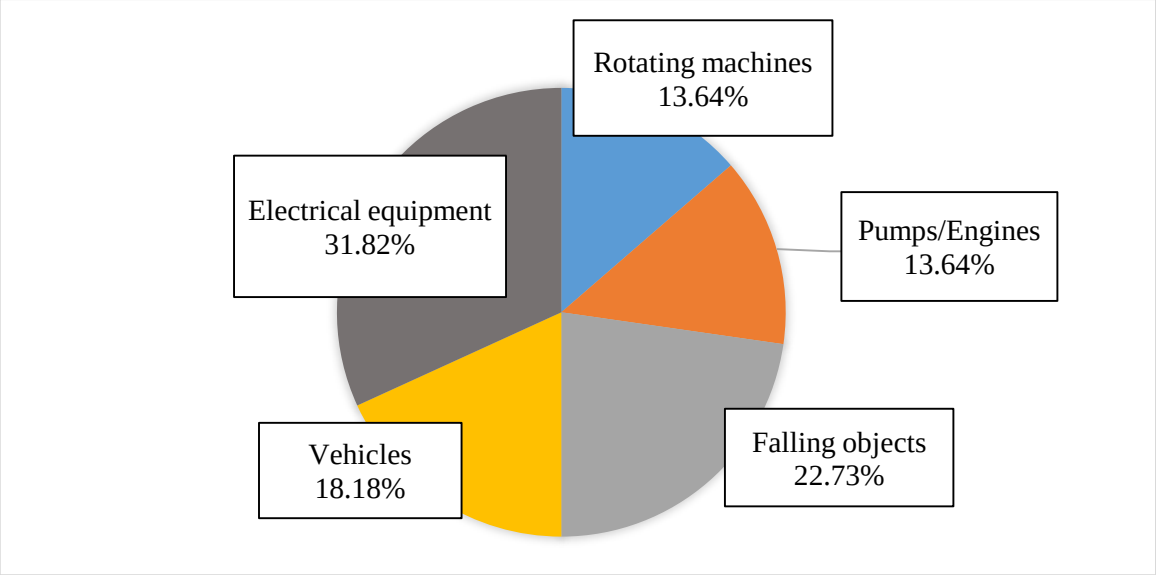

Figure 7. Distribution of Incidents Caused by Lack of Controlling Hazardous Energy Sources by Equipment/Machines

When employees are potentially exposed to the energy sources, lockout should be implemented to de-energize or isolate the energy sources. Figure 7 shows that, among the incidents caused by hazardous energy sources, 13.64% were caused by lacking lockout rotating machines such as drums. When employees conduct maintenance or servicing around rotating machines, the machines should be locked out efficiently to prevent employees from being caught by the machines. 13.64% were caused by the lack of shutting down pumps and engines. 22.73% were caused since employees were killed by accidental falling objects. During maintenance and servicing operations, the objects which can fall and release energy to kill people should be controlled properly. Employers should develop a lockout procedure to at least address that the

objects such as hoist cables, counterweights and coil tubing units should be secured or chained properly prior to operations. 18.18% of the incidents caused by failures of locking vehicles so that employees were killed by the accidental moving of the vehicles. Employers should make sure employee understand hazards associated with the operations near vehicles, and ensure vehicles are locked out properly before their operations. The rest of incidents, which accounted for 31.82% of the personnel incidents, could be prevented if there was an efficient procedure for lockout of electrical equipment. Unlike overhead power lines, electrical equipment could be de-energized without affecting all electricity-driven operations. For example, an employee was involved in repairing a flexible power cable. Before the repairing, electricity should be de-energized to prevent electrocution.

Table 20 shows the subcategories of the process incidents that resulted in deficiency in work practice with corresponding percentages.

Table 20. Subcategories of Deficiency in Work Practice of Process Incidents

Subcategories of Deficiency in Work Practice	Percentage
Lack of/Insufficient work practice for hot work	40.0%
Lack of/Insufficient work practice for operations involving flammable materials	40.0%
Lack of/Insufficient work practice for operations involving hydrogen sulfide/ nitrogen	20.0%

Work practices should be developed for hot work, operations involving potential exposures to hydrogen sulfide and nitrogen, as well as operations involving flammable materials. Table 20 shows that, among the process incidents caused by deficiency in work practice, 40.0% of them were happened during hot work. Employers should develop safe work practices to at least address how to ensure safe conditions to conduct hot work. Only qualified employees can be assigned and employers should contract a third party to conduct if necessary. OSHA General Industry Standards 1910.252 covers requirements regarding hot work such as welding, cutting and brazing, and the standards were cited frequently for the hot work incidents that happened during drilling and servicing operations. Thus when employers develop the safe work practice for hot work, OSHA 1910.252 can be used as a guideline. Another 40.0% of process incidents were caused by the failure to isolate ignition sources during the operations involving any flammable material. Common ignition sources are pump motors and trucks. Thus, employers should develop a safe work practice to identify the operations involving potential releases of flammable materials, such as hot-oiling, drilling, and tripping pipe, and instruct employees how to make sure their operations are isolated with potential ignition sources. Additionally, 20.0% of the personnel incidents were caused by the exposures to hydrogen sulfide and nitrogen. On drilling fields, these materials exist in oil storage tanks and oil wells. Employers shall have safe work practice in place to protect employees from being exposed.

According to the results and discussions above, some drilling and servicing operations, such as hot work, can be conducted frequently, but are associated with hazards that cause fatal incidents. Employers are responsible for developing work practices for these operations to improve safety performances. Employers should establish and implement work practices at least for following operations to protect employees from being exposed to the hazards.

- Operations near overhead power lines
    - Employers should make sure that there are enough clearances when employees are working around overhead power lines. Operations near overhead power lines include, but are not limited to, rigging up derricks and handling drilling pipes.
- Lockout hazardous energy sources, which include but are not limited to
    - rotating machines and equipment such as drums
    - pumps and engines
    - potential falling mechanical parts such as counterweights and hoist cables
    - powerful vehicles
    - energized electrical equipment
- Isolation of ignition sources during the operations involving flammable materials
- Hot work
- Operations involving potential exposures of hydrogen sulfide and nitrogen

3.3.8 Training

According to Figure 4, 17.27% of personnel incidents and 8.82% of process incidents were caused by deficiency in training. The data is also shown in Table 21.

Table 21. Percentage of Personnel/Process Incidents Caused by Deficiency in Training

	Training
Personnel Incidents	17.27%
Process Incidents	8.82%

Table 22 shows the subcategories of the personnel incidents caused by deficiency in training.

Table 22. Subcategories of Deficiency in Training of Personnel Incidents

Subcategories of Deficiency in Training	Percentage
Lack of/ Insufficient training for truck/forklift/trailer operations	34.21%
Lack of/ Insufficient training for operations near electrical equipment	21.05%
Lack of/ Insufficient training for written procedure	15.79%
Lack of/ Insufficient training for fall protection equipment	13.16%
Lack of/ Insufficient training for hazard communication	7.89%
Miscellaneous	7.89%

34.21% of the personnel incidents were related to inadequate training of truck/forklift/trailer operations. Operators of the vehicles should be instructed on operations vehicles and loading/unloading/lifting equipment safely and only competent operators should be assigned to conduct the operations. Also, operators should understand safe work practice to lockout moving vehicles when any other employees are working around the vehicles or when the operators get down from vehicles to conduct any other task. 21.05% of the personnel incidents were caused by inadequate or lack of training about safe work practice of operations near electrical equipment. Thus training should be provided for the safe work practice to prevent or reduce electrocution. 15.79% of incidents indicate that adequate training for operating procedures is necessary, and the operating procedures which require adequate training should at least include the procedures for drilling, rigging, tong operations, chain operations, and activities involving reseating/removing horseheads and so on. 13.16% of them were resulted in deficiency in training for fall protection

equipment. Employees should be trained to understand potential fall hazards and how to use PPE in proper manners. And 7.89% of incidents indicate that training for hazard communication is needed since it ensures employees can be informed about hazards efficiently. Employees should be trained to conduct signaling effectively, understand the hazards associated with their operations, and take proper measures to protect themselves from the hazards. 7.89% of miscellaneous incidents indicated training is necessary before an employee is assigned to a task.

On the other hand, Table 23 shows the subcategories of process incidents that caused by deficiency in training.

Table 23. Subcategories of Deficiency in Training of Process Incidents

Subcategories of Deficiency in Training	Percentage
Lack of/ Insufficient training for hazard communication	50.0%
Lack of/ Insufficient training for operations of high-pressure equipment	33.33%
Lack of/ Insufficient training for truck operation	16.67%

50.0% of the incidents were caused by inadequate training for hazard communication. Employees did not realize the chemical hazards involving their work areas and were exposed to fire/explosion hazard and asphyxiation hazard. Training of hazard communication is necessary to ensure employees understand the hazards they may be exposed to and understand measures to protect themselves. 33.33% of them were caused by inadequate training for the operations of high pressure equipment. Employees should be instructed properly to understand potential high-pressure hazards and follow relevant procedures to perform their tasks safely. 16.67% of the incidents was caused

by inadequate training of truck operations, so that a truck operator clipped the truck tire on a gas line, leading to an accidental gas release.

According to results and discussions above, it can be found that training is an important component of the management system since employees can understand the hazards associated with their operations and act in safe manners via adequate trainings. Employers should establish a training program and ensure that:

- Employees involved in operations are adequately trained and understand the hazards associated with their operations.
- Training is provided for each employee who might be exposed to hazards, and training should be at least provided for,
    - using PPE
    - safe work practice of truck/forklift/trailer operations
    - safe work practice of operations near electrical equipment
    - operating procedures
    - hazard communication

3.3.9 Emergency Response Planning

According to Figure 4, causal factors of 7.35% of process incidents and 1.82% of personnel incidents could be identified as deficiencies in emergency response planning. The data is also shown in Table 24.

Table 24. Percentage of Personnel/Process Incidents Caused by Deficiency in Emergency Response Planning

	Emergency Response Planning
Personnel Incidents	1.82%
Process Incidents	7.35%

Considering that emergency response planning is similar for personnel incidents and process incidents, the discussion of the management element is not separated for process and personnel incidents. Deficiencies in emergency response planning include

- improper rescue resulting in second harm to the injured employee
- improper rescue resulting in the fatality of an additional employee who is trying to rescue
- failures to access emergency escape routes
- lack of qualified people to respond emergency case onsite

Subcategories of all incidents caused by deficiency in emergency response planning is shown in Table 25.

Table 25. Subcategories of Deficiency in Emergency Response Planning of Process and Personnel Incidents

Subcategories of Deficiency in Emergency Response Planning	Percentage
Failures to access emergency escape route	33.33%
Second harm by coworkers	22.22%
Improper rescue causing additional fatality	22.22%
Lack of qualified people to respond emergency onsite	22.22%

Table 25 shows that 33.33% of both process and personnel incidents were caused because employees could not access emergency escape routes. Many drilling and servicing operations are conducted on high derricks, thus it is hard for employees to escape during emergency cases. In order to make emergency response efficient, a Geronimo Emergency Escape Line should be installed properly, and permits fast emergency exit from working platform to safe place. 22.22% of the incidents were caused because of second harm by coworkers. Another 22.22% of incidents were caused when employees were trying to rescue their coworkers, but they were also exposed to the same hazards and died. These incidents indicate that all employees should be given instructions on emergency response, so that second harm and additional fatalities can be prevented. Additionally, 22.22% of incidents were caused because there was lack of qualified people to respond emergency case onsite. Considering drilling fields are remote and may be hard to reach emergency services in short time, qualified people to conduct first-aid should be onsite. Also, a qualified operator should be ready to stop energy sources, such as disengaging pumps, when there is an emergency case.

Based on the results and discussions above, employers should implement an emergency response planning program, and the program should at least address that:

- All employees should be instructed on emergency response, to avoid a second harm and an additional fatality.
- A Geronimo Emergency Escape Line should be installed properly to make sure employees can exit from derricks during emergency cases.
- Qualified people to respond emergency cases should be onsite to stop energy sources.
- Qualified first-aid people should be onsite.

3.3.10 Environment

Since drilling and servicing operations are conducted outside, environment factors such as rain, strong wind, and lightning can be causal factors of incidents. According to Figure 4, 1.82% of personnel incidents and 2.94% of process incidents were related to environmental factors. The data is also shown in Table 26.

Table 26. Percentage of Personnel/Process Incidents Caused by Environment

	Environment
Personnel Incidents	1.82%
Process Incidents	2.94%

Out of the personnel incidents, 75.0% were electrocution, and 25.0% were struck-by events. Employees were exposed to struck-by hazard when strong wind was able to blow ropes/chains to strike employees. Additionally, employees were exposed to electrocution hazard when lightning

storms destroyed the isolation of electrical cables or boxes, and left the electrical parts in a wet condition. Thus, employers need to identify the potential hazards related with environmental factors. These factors should be considered when employers establish safety programs.

All process incidents were fire and explosions since lightening ignited fumes of flammable materials, which were stored in tanks or which were being transferred. Thus, employers should take measures to prevent the hazard, for example, by improving their inherent designs and hazard assessment to identify similar scenarios and isolate flammable materials from lightening, or by improving their training to make employees understand the hazards and avoid transferring flammable materials when there is a lighting storm.

Environment is one of causal factors for fatal incidents, but it is not a management element. It is related with other management elements. When employers develop safety programs for each safety management element, this factor should be taken into account.

3.3.11 Others

According to Figure 4, causal factors of 9.09% of personnel incidents could not be categorized into any other candidate management element. Causal factors of the incidents need to be studied deeper to identify the underlying management issue. Based on the information provided by the database, it is hard to determine the categorizations of the causal factors.

3.4 Limitation of the Study

The safety management system developed from the study is a goal-oriented management system, which is similar to OSHA PSM and BSEE SEMS. The fatal incident data that was analyzed in the

study covers variable drilling and servicing operations. Details about how industries conduct these drilling and servicing operations require expert knowledge and cannot be known by studying the database only. Thus, the goal-oriented management system was developed to provide guidelines for industries to improve safety performances. More prescriptive safety programs are needed to be established by industries according to how industries conduct their operations.

Some management elements that covered in OSHA PSM or BSEE SEMS, such as incident investigations, auditing and record keeping, are not covered in the developed safety management system. The reason is that the developed system are generated based on the incident database. The database does not reflect any deficiency of those elements. These elements are recommended to be considered separately and they can be incorporated into the current safety management system.

Additionally, OSHA does not either provide full investigation reports of incidents to the public, or provide root causes of incidents in OSHA public database. Expert knowledge and judgment are used to identify those causal factors of incidents which are implied by incident descriptions. Thus, the frequencies and percentages, which are used to describe the incidents related to the management elements, are with uncertainties. However, the quantitative analysis is adequate to reflect the safety hazards associated with drilling and servicing operations, and the safety management program that developed according to the analysis can be used as guidelines to help oil and gas industries improve their safety performances. In order to conduct a precise analysis about the causes of incidents in the future, OSHA investigation reports are strongly recommended to be accessible for researchers.

4. SUMMARY AND FUTURE WORK

Texas drilling and servicing operations are only governed by OSHA General Industry Standards, OSHA Construction Standards, and General Duty Clauses. Since General Industry Standards and Construction Standards do not adequately address the hazards associated with drilling and servicing operations, a safety management system has been developed for the operations in order to improve safety performances. OSHA PSM and BSEE SEMS are two safety management systems which may be reasonable to be extended to drilling and servicing operations within the OSHA jurisdiction area in Texas. However, based on the study of fatal incidents and literature review, extending either of the two safety management systems is not the best solution to reduce fatalities related to drilling and servicing operations. Instead, a safety management system has been developed by comprehensively studying causal factors of fatal incidents, and both process safety and personnel safety are integrated into the safety management system to fit the nature of drilling and servicing operations. The safety management system covers the frequent violated OSHA standards as well as fills the gaps of the OSHA General Industry Standards and Construction Standards.

The developed safety management provides a framework to guide industries to build safety programs. It contains nine elements, which are PPE, Equipment Design/Selection, Inspection and Maintenance, Written Procedure, Hazard Assessment, Hazard Communication, Work Practice, Training, and Emergency Response Planning. All these elements were studied from the aspects of process incidents and personnel incidents, and recommendations for each management element were summarized. Considering environment factors such as rain, strong wind and lightning may

lead to fatal incidents, the environment factors should be taken into account when employers develop their safety programs.

OSHA database does not provide root causes of fatal incidents, thus it is hard to distinguish whether an incident is caused by employer's safety management issue or human factors. Besides effects of safety programs, employees' performances depend on the nature of tasks, qualification of individuals, and safety culture of their industry. In the future, the contribution of human factors to safety performances of drilling and servicing operations should be studied and human factors are recommended to be incorporated into the developed safety management system.

Some management elements covered in OSHA PSM or BSEE SEMS, such as incident investigations, auditing, and record keeping, are not covered in the developed management system since the incident database does not provide any information related to these elements. They are recommended to be considered separately and incorporated in the developed safety management system.

The developed safety management system provide a guidelines for industries to set up safety programs. In order to evaluate whether safety programs of industries are effective to comply with the safety management system, metrics for the management elements should be developed in the future. Appropriate safety metrics can reflect the deficiencies of current safety programs and help industries to make improvements on their safety programs.

Additionally, most drilling and servicing operations are conducted by contractors. Small contractor industries may not have enough abilities to develop safety programs to comply with safety

management systems, thus, owner industries may take the responsibilities to develop safety programs. In the future, there should be studies on contractor management to provide guidelines for contractor and owner companies, and make sure contractors and owners are on the same page regarding safety programs. If a contractor industry does have its own safety program complying with the safety management system, it is also important to ensure that there is no conflict between the safety programs of the contractor and its owner.

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