Using Historical Data & Engineering Economy to Predict Future Events

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Abstract

It is customary to utilize historical data to predict future events. This study addresses the issue of safety in the petroleum industry and how safety culture can potentially influence the state of health and safety systems of different companies. It includes a comparison of the safety cultures of two large oil companies before and after they experienced major incident utilizing integrate management information system (IMIS) data base from Occupational Safety and Health Administration (OSHA) website; the two major incidents are the Exxon Valdez incident of 1989 and the British Petroleum (BP) -Gulf of Mexico oil spill of 2010. It was discover that, increasing OSHA inspections at Exxon after the Exxon Valdez accident has lead to the reduction of violations. Furthermore, fines attributed to safety violations found was higher after Exxon Valdez incident than before. For the total of inspections held by OSHA officers at BP and Exxon from 1973 to 2010, more safety violations were observed at BP, 82%, which was greater than the percentage of violations at Exxon, 66%. Standards related to process safety management of highly hazardous chemicals and general requirement standard were the top two violations in both companies. It is hypothesized that the number of safety violations at BP after the deep water horizon in 2010 will follow approximately the same path as observed at Exxon after the Valdez incident. The reinforcement of process safety management of highly hazardous chemical will improve incontestably the safety state in both companies.

Introduction

The petroleum industry is one of the most hazardous industries where major catastrophes can unexpectedly occur. Several accidents occurred in the recent decades in the petroleum industry. It has been confirmed that explosions cause the greatest proportion of losses in the chemical process industry. There are an estimated 67.7% against 30.2% losses caused by fires and 2.1% by toxic releases (Lees, 1996; Mannan, 2005). An explosion is a rapid increase in the volume and release of energy in an extreme manner according to Lees (1996) and Mannan (2005), usually with the generation of high temperature and the release of gases. An explosion is usually a result of safety failures that will cause fatal and catastrophic events. Also, Crowl, in 2002, defined “explosion” as a rapid expansion of gases resulting in a rapidly moving pressure or shock wave. Consequences of explosions are usually fatal to people, can cause loss of equipment, and can cause major damages to the environment. To minimize future explosions in the petroleum industry, it is important to analyze past accidents in general, evaluate the health and safety systems, identify deficiencies in the safety systems, and propose corrective actions. The severity of loss resulting from explosions has enhanced research interest in this area.

Previous research interest was focused on examining the facts, causal factors, and sequence of events leading to explosions in past accidents. The outcome of this search was a suggestion of corrective action to avoid or mitigate future explosions and loss. Safety culture is an important research factor to take into consideration to increase safety in the work environment. The safety culture of an organization is the product of the individual and group values, attitudes, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization’s health and safety program (Rao, 2006). In this study the safety culture was measured as a function of safety violations found during OSHA officer’s inspection. Learning from incidents is a fundamental approach in accident prevention.

Besides injury reports, there are plenty of publications that share insights from causal analysis of major incidents, and many of them have identified cultural issues that led to the incident. Even though learning from incidents is fundamental, the complexity of safety culture and major incidents calls for a more holistic approach. Goh, et al. (2009) found that the use of systems thinking underlying systemic structures creates and sustains poor safety culture that can contribute to the occurrence of major incidents. One strategy to avoid accidents is to be continuously vigilant through the use of safety indicators.

Often, hindsight has shown that if signals or early warnings had been detected and managed in advance, the unwanted event could have been prevented. This includes, e.g., the accident at the Esso natural gas plant in Longford, Australia in 1998, killing two workers (Hopkins, 2000), and the accident at the BP Texas City refinery in 2005, killing 15 workers (Baker, et al.., 2007). Recognizing signals, early warnings through the use of proactive safety indicators will reduce the risk of such major accidents (Gog, et al., 2009).The term culture is clarified as it is typically applied to organizations, to safety, and particularly to petroleum industry safety. Some clarification in terms of positive safety culture, safety culture models, and levels of aggregation and safety performance is provided by presenting appropriate empirical evidence and its theoretical developments. In general, safety culture is designed to influence employees' attitudes and behaviors in relation to an organization's ongoing health and safety performance (Choudhry, 2006). Also, Neal and Griffin (2002) presented a model identifying the linkages between safety climate, safety knowledge, safety motivation, and safety behavior demonstrating that knowledge and motivation mediate the relationship between safety climate and self-reported safety compliance and participation. Cox and Cheyne (2000) described the development of two elements of a toolkit, which combines audits with questionnaires assessing employees' perceptions and attitudes.

Mohamed (2003) promoted adopting the balanced scorecard tool to benchmark organizational culture in construction and argued that selecting and evaluating measures in four perspectives: management, operational, customer, and learning, would enable organizations to pursue incremental safety performance improvements. The balance scorecard is an organizational framework for implementing and managing strategy at all levels of an enterprise by linking objectives, initiatives, and measures to an organization's strategy. The scorecard provides an enterprise view of an organization's overall performance. It integrates financial measures with other key performance indicators around customer perspectives, internal business processes, and organizational growth, learning, and innovation. Moreover, Kennedy and Kirwan (1998) focused on aspects of safety management practices, called the safety culture hazard and operability (SCHAZOP), and provided a qualitative analytical approach to identify detailed vulnerabilities and the means for their prevention. Rao, in 2006, used Curtailing Accidents by Managing Social Capital (CAMSoC), an accident analysis model, to illustrate five accidents: Bhopal (India), Hyatt Regency (USA), Tenerife (Canary Islands), Westray (Canada), and Exxon Valdez (USA). He came out with two key socio-management insights: the biggest source of motivation that causes deviant behavior leading to accidents is "Faulty Value Systems". The second biggest source is "Enforceable Trust". From a management control perspective, deterioration in safety culture and resultant accidents are more due to the action controls rather than explicit "Culture Control". Accidents can cause a sudden slump in the value of the company stock owing to financial problems; this has certainly prompted some companies to correct any defects in the company culture which is the root cause of the accidents. However, more studies such as this need to be developed to enhance safety culture in some companies, such as BP which still neglects the values of the safety culture.

Whittingham (2008) emphasized the fact that culture is based on assumptions. Clearly, particularly in the case of a safety culture, it is advantageous to recognize a cultural mismatch before the occurrence of an accident or catastrophe. However, the reality is that in the absence of such an event, it will always be easier and less disruptive to continue under the old culture. It is unfortunate that it often takes a major event to precipitate a fundamental examination of the organization's culture. At this point, the company becomes a learning organization, one which no longer relies on major events to be the instrument of change, but sees the need for continuous improvement in order to keep ahead of events or accidents (Whittingham, 2008). This study intends to compare the safety culture of two large oil companies before and after these companies' experienced major incidents. The two major incidents are the Exxon Valdez of 1989 and the British Petroleum (BP)-Gulf of Mexico oil spill of 2010. The choice of those two incidents is justified by the fact that Exxon has the reputation of being the largest petroleum company in the world, and BP is recognized as an oil giant. Both incidents involved tremendous losses. Also, they have been in the center of repetitive catastrophes and fatalities over the past decades.

At around midnight on March 24, 1989, the 987-foot tank vessel *Exxon Valdez* struck aground on Bligh Reef, Prince William Sound, Alaska. At the time of the grounding, the *Exxon Valdez* was loaded to a draft of 56 feet. The charted depth where the vessel grounded was 30 feet at low tide. The severity of the grounding is attributed to the sound's rocky bottom, coupled with the vessel's momentum. Subsequent damage surveys showed that eight of the 11 cargo tanks, extending the full length of the vessel, were torn open. Three salt-water ballast tanks also were pierced. A total of 11 tanks on the center and starboard side of the vessel were damaged. The enormous damage caused a rapid loss of cargo. Within five hours, 10.1 million gallons had been spilled. About 80 percent of the ship's cargo remained on board, and the vessel came to rest in a very unstable position. The oil slick scattered over 3,000 square miles and onto over 350 miles of shoreline in Prince William Sound alone (Skinner & Reilly, 1989). The Exxon Valdez oil spill caused immense long-term losses to the fish, tourism, and sea ecology apart from fouling up more than 1,000 miles of beach in south central Alaska. There were no deaths directly as a result of the accident; however, four lives were lost during the clean-up operation. The immediate cause was a steer right command given by the third mate. The underlying factors of an alcoholic captain and crew change violation led to one of the world's worst oil-spill disasters (Rao, 2006). Approximately 20 years after the Exxon Valdez incident, on April 20, 2010, a sudden explosion and fire occurred on the BP-Transocean Deepwater Horizon oil rig. The accident resulted in the deaths of 11 workers and caused a massive oil spill into the Gulf of Mexico. The rig was located approximately 50 miles southeast of Venice, Louisiana, and had a 126-member crew onboard. The accident involved a well integrity failure followed by loss of hydrostatic control of the well. This was followed by a failure to control the well with the blowout preventer (BOP) equipment which allowed the release and subsequent ignition of hydrocarbons. Ultimately, the BOP emergency functions failed to seal the well after the initial explosions. The BP team used fault tree analysis during the course of investigation to define and consider various scenarios, failure modes, and possible contributing factors (BP, Accident Report, 2010).

The culture of BP and of its plant in Texas City, Texas, in particular, was a culture of blindness to major risk. BP employees were generally unaware of and insensitive to risk. BP refining was actively engaged in what it described as a "*culture change program*''; it was seeking to transform its culture into that of a high-reliability organization (HRO). HROs practice principles of organizing that reduce the pain created by unexpected events (Weick & Sutcliffe, 2007). But at the BP Texas City refinery, the HRO program had not succeeded. After the accident, on July 27, 2010, the British Chief Executive Officer of BP, Anthony Bryan Hayward, resigned and was replaced by the American Bob Dudley on the 1st of October 2010. Bob Dudley, on June 23, 2010, was appointed President and Chief Executive Officer of BP's Gulf Coast Restoration Organization working with the oil leakage in the Gulf of Mexico, which affects five US states, Louisiana, Alabama, Mississippi, Florida, and Texas. This new change in BP leadership will, hopefully, raise the safety culture at BP. These are changes that can be expected to move BP in the direction of the HRO culture to which it aspires (Hopkins, 2009). In this study, emphasis was placed on the comparisons of the safety culture between the Exxon and BP activities <u>before</u> and <u>after</u> the Exxon Valdez oil spill, and the current safety state of the BP Gulf of Mexico incident. The first objective was to measure safety culture based on Occupational Safety and Health Administration (OSHA) inspections and safety violations recorded in the OSHA Integrated Management Information System (IMIS) database; the second objective was to come out with the safety culture change that Exxon went through as a result of their incident. The final objective was to extrapolate the result obtained with Exxon to predict BP's expected change in its safety culture as a result of its incident. This expectation of culture change acts as a measure to see how closely BP's change will coincide with our expectations. Suggestions of corrective actions and recommendations based on this comparison were addressed.

Materials and Methods

The main analysis of safety systems at BP and Exxon was based on the OSHA fines related to safety violations. The information was collected from the OHSA Integrated Management Information System (IMIS) database for the period before and after the Exxon Valdez accident for Exxon and before the BP Gulf of Mexico accident for British Petroleum. The OSHA IMIS was designed as an information resource for in-house use by OSHA staff and management, and by state agencies which carry out federally-approved OSHA programs. Access to this OSHA work product is being afforded via the Internet for the use of members of the public who wish to track OSHA interventions at particular work sites or to perform statistical analyses of OSHA enforcement activity. This study utilized the establishment search under the IMIS database on the OSHA.gov web site, under the "Data & statistics" and in the "Establishment Search" link.

Steps describing how to recover data related to safety violation fines by company are located in Appendix 1. All past OSHA inspections were scrupulously analyzed from the IMIS database. The number of inspections was recorded. Inspections with the history of violations were extracted; the corresponding fines as well as the type of violations were recorded on the table. These fines are funds paid to OSHA as punishment for noncompliance or violation of standards set forth by OSHA. The evaluation of a safety system was done based on the OSHA fines and safety violations recorded in IMIS data base. To compare fines paid back in 1989 to fines paid today, a fair evaluation of fines was taking into consideration the US inflation rate with 2010 as a reference year. The following mathematical formula was used:

$$(R\$)_K = (A\$)_K \, [1/ (1+f\,)]^{K-b}$$

(Blank, L. 2005)

Where:

- A$: represents the actual dollars. It provides information on the actual money quantities.
- R$: represents real dollars in terms of purchasing power at some stated time period (in this study, the base year will be fixed at 2010). It provides information in terms of a constant purchasing power.
- b: represents a base period (2010). It is the purchasing-power time reference.
- *f*: represents a general price inflation. It measures the change in purchasing power from one time to another
- K: represents the actual year.

Safety fines corresponding to a specific violation at Exxon and BP from 1973 to 2010 were recorded; Histograms, linear regression, and time sequence plot were utilize to show the variability of safety violations as well as fines at BP and Exxon from 1989 to 2010.

Statistical Analysis

Histograms and time sequence plot were used to analyze and compare the number of inspections, violations, and fines at BP and Exxon from 1989 to 2010.Also a multiple regression model was used to predict the evolution of the safety culture at BP after the oil spill, based on the results obtained from Exxon.

The following model was used:

$Y= \beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon_i$

Where: X_1, X_2, $X_{3\ldots}$ and X_k are quantitative independent variables such as violations found during OSHA inspections, and fines.

Y: a specific year

β: is a coefficient called partial slop

Results:

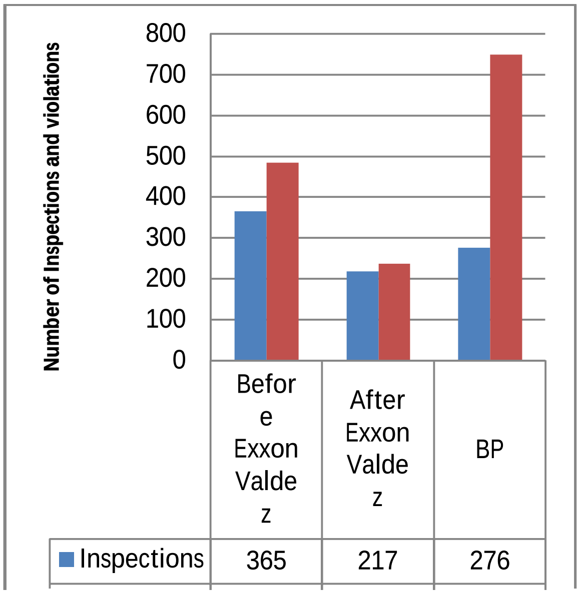

Figure 1: Inspections and violations before and after Exxon Valdez and at BP from 1973- 2010

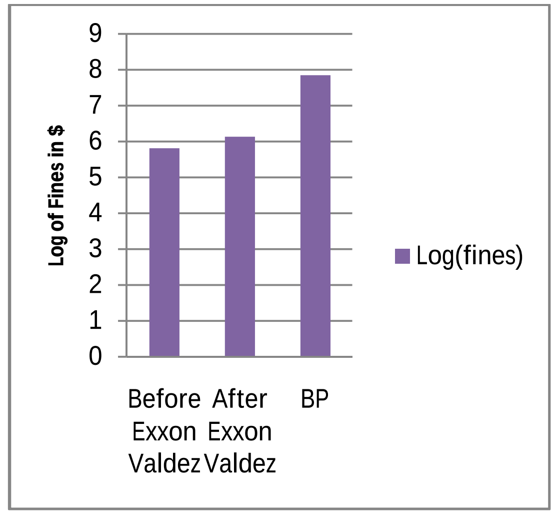

Figure 2: Fines at Exxon before and after Valdez and at BP {Log (fines)}

Taken together, figure 1 and figure 2 show that, the increasing in inspections by OSHA inspectors at Exxon after the Exxon Valdez accident led to a reduction in the number of violations. Furthermore, fines corresponding to violations had increased exponentially; this can be justified by the reinforcement of safety standard by OSHA, Environmental Protection Agency (EPA), as well as other regulatory agencies. Those fines are $646563.63; $1,326,012.73 and $68,132,507 respectively before Exxon Valdez from 1973 to1989, after Exxon Valdez 1990 to 2010, and at BP from 1973 to 2010.

Analysis of Safety Standards, Violatied Before and After 1989. The following code is considered for the rest of data analysis.

A. = *19100252 D02 IV General Requirements*
B. =*19100119 E05 Process safety management of highly hazardous chemicals*
C. = *19100106G03 IV Flammable and combustible liquids*
D. = *19101200 G06 Hazard Communications*
E. = *19100145 C03Specifications for accident prevention signs and tags*
F. = *ARM001103 A Occupational Injuries/Illness Record Keeping*
G. = *19100151 B Medical services and first aid*
H. = *19040002 A Partial exemption for establishments in certain industries*
I. = *19100134D02 II Respiratory protections*
J. = *19100305 B01 Wiring methods components and equipment for general use*
K. = *19100242 A Hand and portable powered tools and equipment general*
L. = *19100215 A04 Abrasive wheel machinery*
M. = *1903002 A posting of notice; availability of the act, Regulations and applicable standards*
N. = *TRAINING*
O. = *19100023 B01 Guarding floor and wall openings and holes*
P. = *19100037 Q01 Maintenance, safeguards, and operational features for exit routes*
Q. = *1926 Subpart K- Electrical*
R. = *19100157 A05 Portable fire extinguishers*
S. = *19100024 H Fixed industrial stairs*

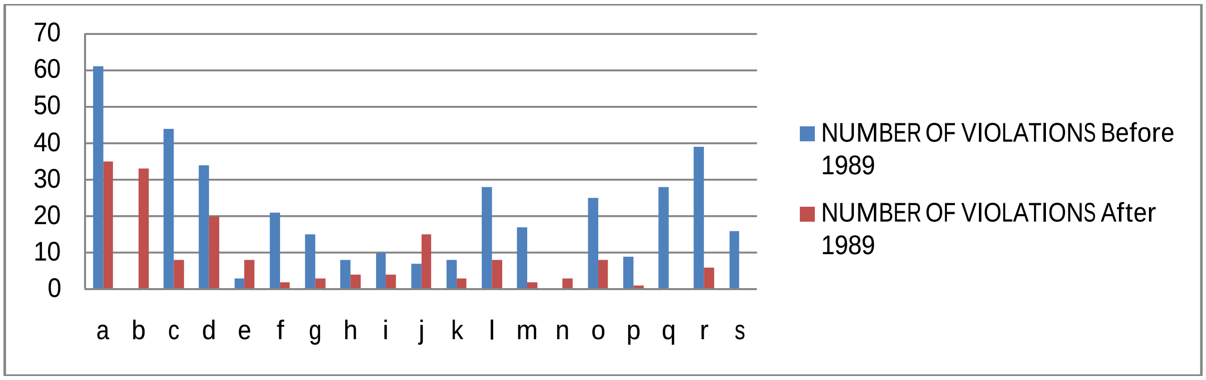

Figure 3: Comparison of the type and quantity of safety violations committed by Exxon before and after 1989 Exxon-Valdez

Figure 3 represents the number of violations before and after 1989. It demonstrates that, the number of safety violations decreased considerably after the Exxon Valdez accident in 1989. Safety violations such as general requirement (a), flammable and combustible liquid (C), accident prevention signs (e), abrasive wheel machinery (l), and portable fire extinguishers hazard have decreased drastically after the accident. There was no safety violations related to process safety management of highly hazardous chemical (b) before the Exxon incident. Also, safety violations such as electrical (Q) and fixed industrial stairs have completely disappeared after the Exxon Valdez incident.

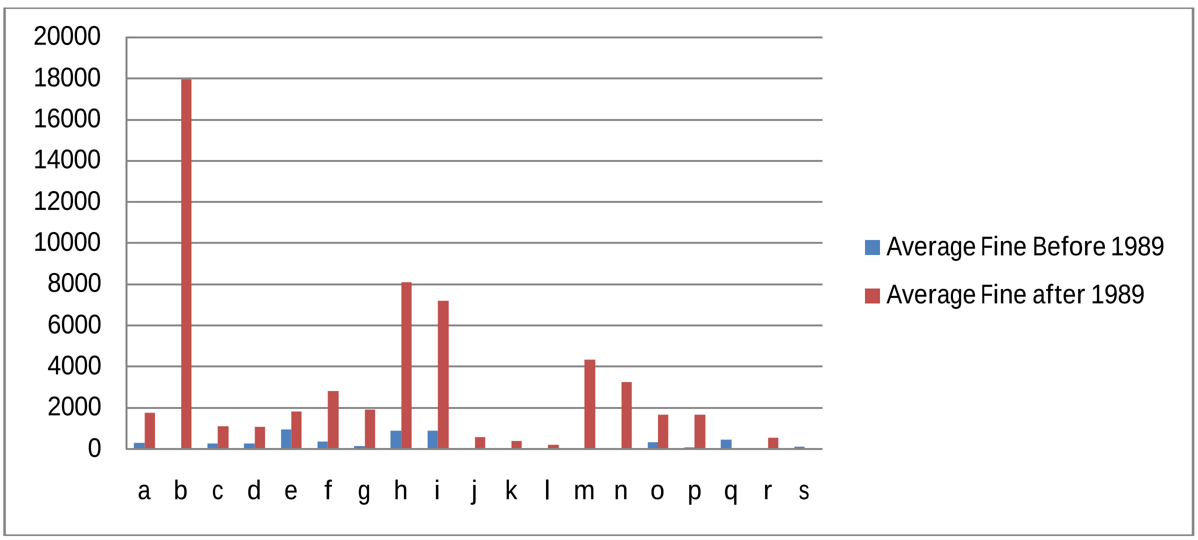

Figure 4: Histogram of averages Fines by violations at Exxon before and after Exxon Valdez

Figure 4 shows that, the average fines by violations have increased considerably after the Exxon Valdez accident in 1989. The average fines related to Process safety management violation was around $18000 by violation.

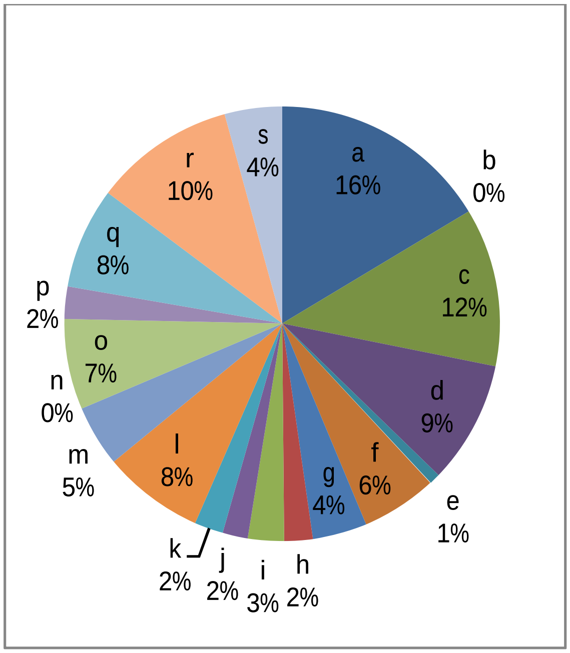

Figure 5: Pie chart of violations at Exxon Before 1989

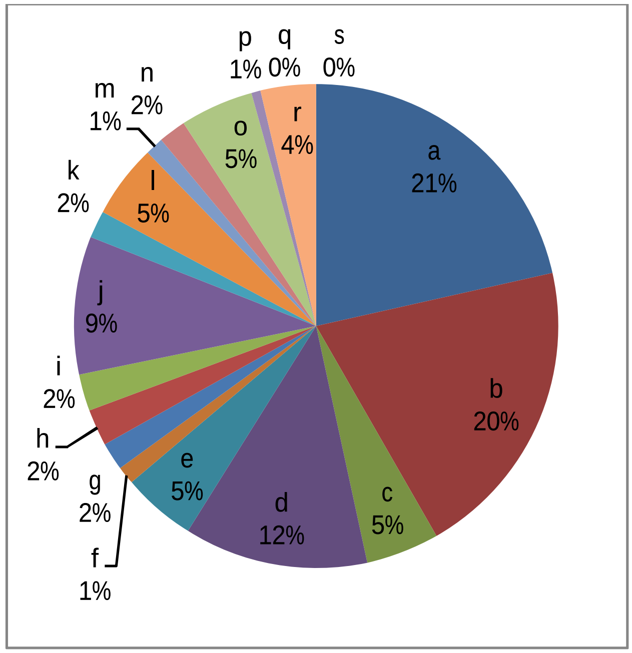

Figure 6: Pie chart of Violations at Exxon After 1989

Figure 5 and 6 represent a percentage

The consequence of this raise of fine had forced Exxon to enforce his safety system of violations by standard before and after the Exxon Valdez incident. For the total violations found at Exxon from 1973 to 2010, the violation related to general duties clause or general requirement was on top with 21% of the total of major violations found; this specific violation has decreased to 16% after the Exxon Valdez incident.

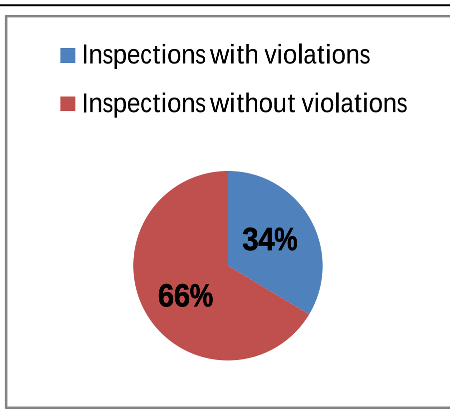

Figure 7: Pie chart representing Exxon's inspections with violations and without violations from 1973- 2010

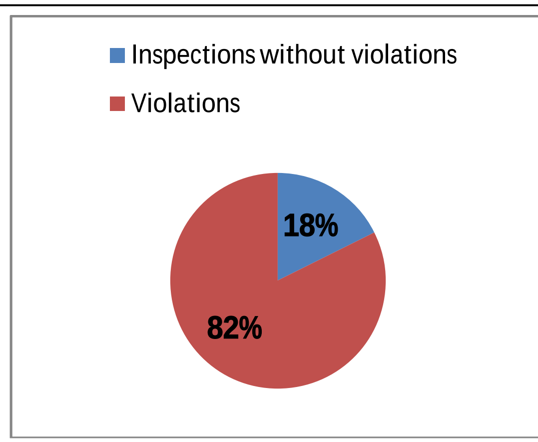

Figure 8: Pie chart representing BP's inspections with violations and without violations from 1973-2010

Figure 7 and Figure 8 represent the proportion of violation and non-violations among inspection done at Exxon end BP by OSHA from 1973 to 2010.More safety violations were observed at BP, 82%,which was greater than the percentage of violations at Exxon, 66%.There is evidence that safety culture at BP is inferior to the safety culture at Exxon.

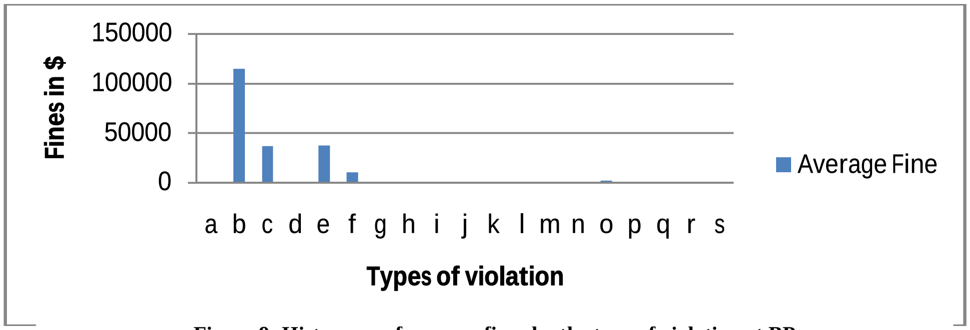

Figure 9: Histogram of average fines by the type of violation at BP

Figure 9, a vertical chart represent the average fine by violations. Fines corresponding to process safety management for highly hazardous chemicals were the highest at BP.

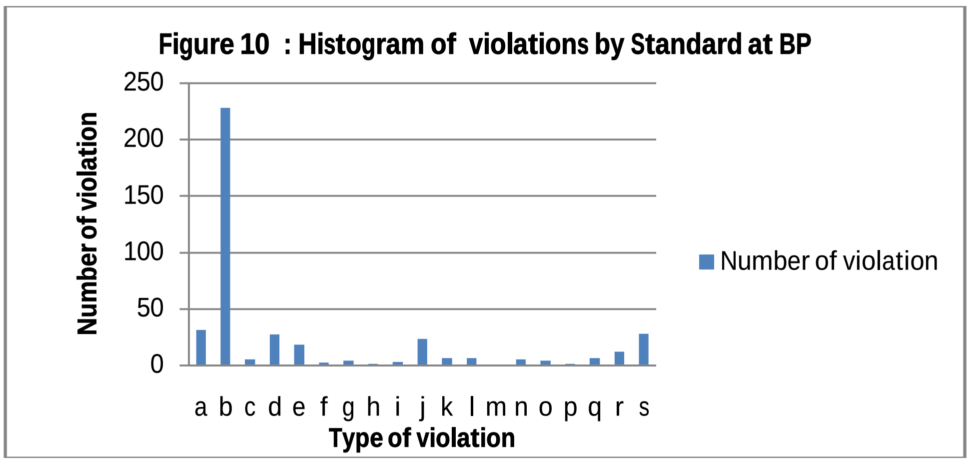

Figure 10 represents the frequency of standards violated from 1971 to 2010. Violations corresponding to process safety management for highly hazardous chemicals were the highest at BP.

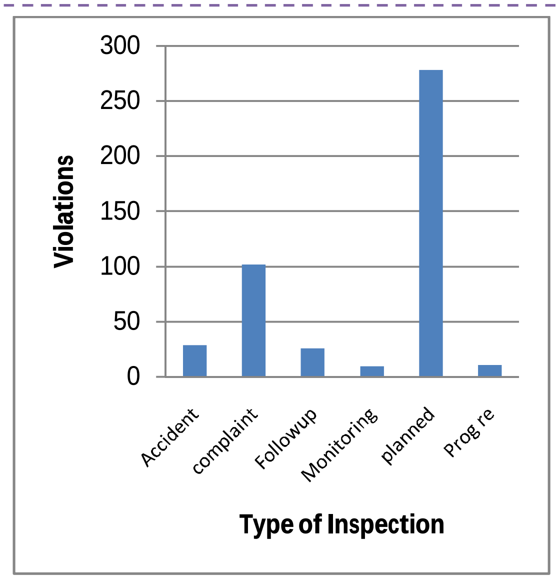

Figure 11: BP's violations by the type of inspection

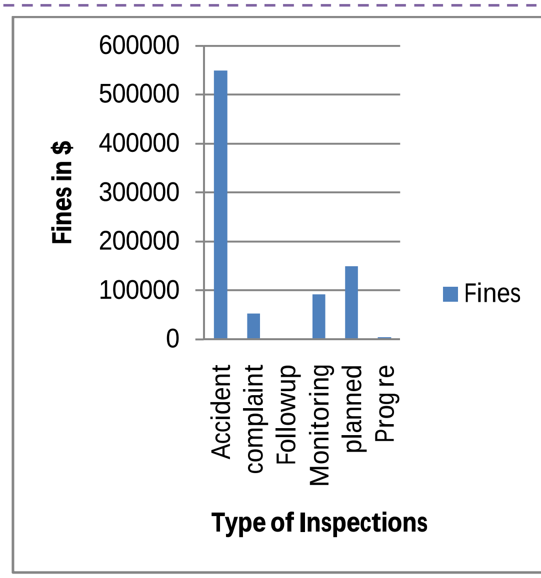

Figure 12: BP fines by the type of inspection

Figure 11 and figure 12 represent respectively, the number of violation and fines at BP. Fines related to violations found during inspections following accidents are very high; these fines can be reduced at BP by the reinforcement of the accident prevention program and engineering control. In the contrary, the majority of violations were found during planned inspections.

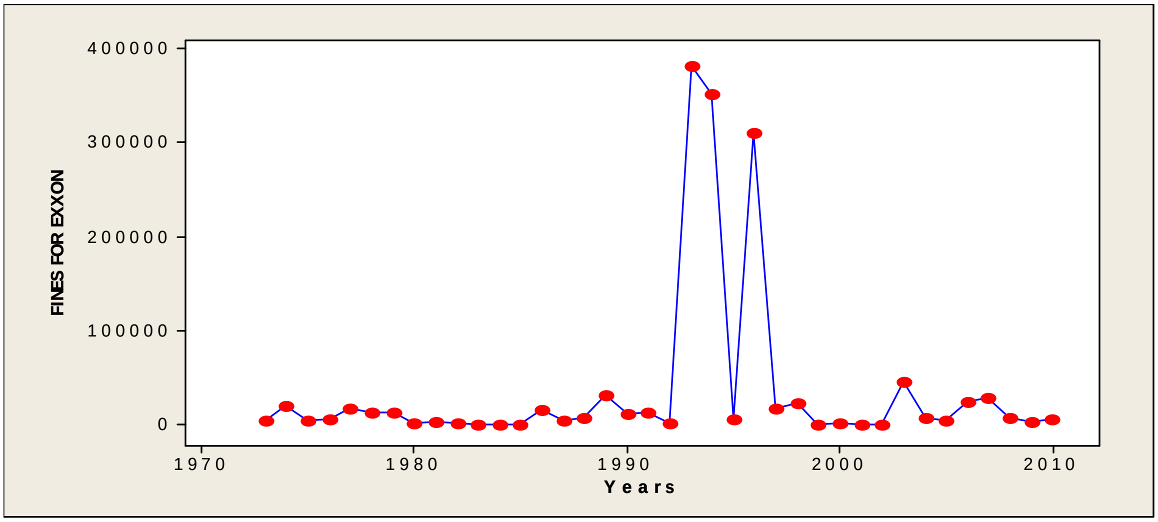

Figure 13: Scatter plots of fines related to safety violations at Exxon From 1973-2010

Figure 13 represent the time sequence plots of fines at Exxon from 1973 to 2010. Fines at Exxon had drastically increased after 1990. This rises of fines can be explained by the reinforcement of safety regulations and safety standards by regulatory agencies.

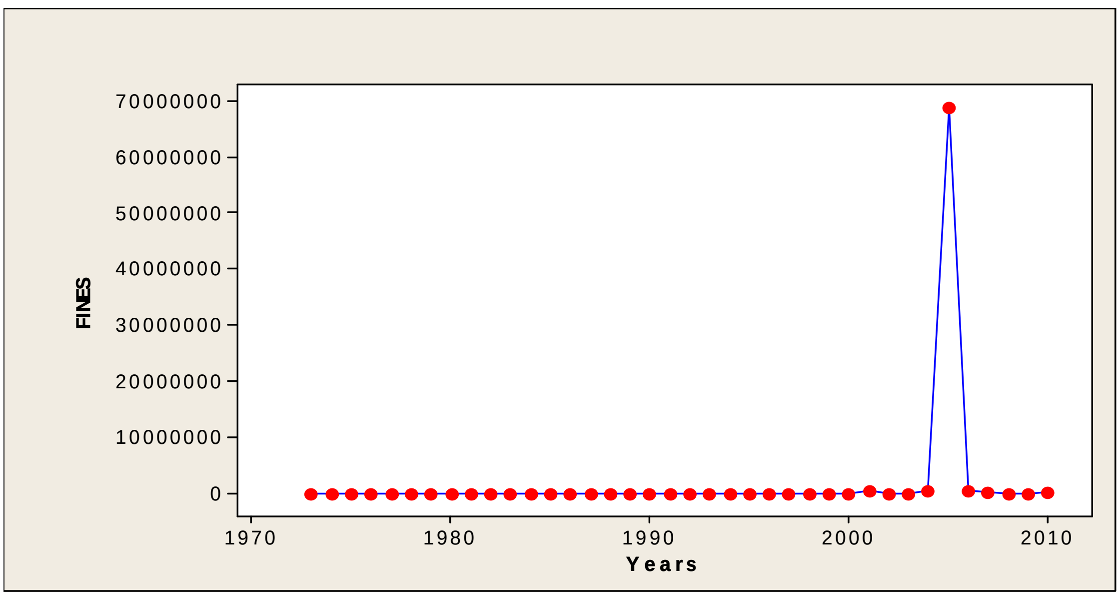

Figure 14: Scatter plots of fines related to safety violations at BP

Figure 14; represent a time sequence plot of fine at BP. A huge pick in 2005 represent fines attributed to BP after the Texas City refinery explosion.

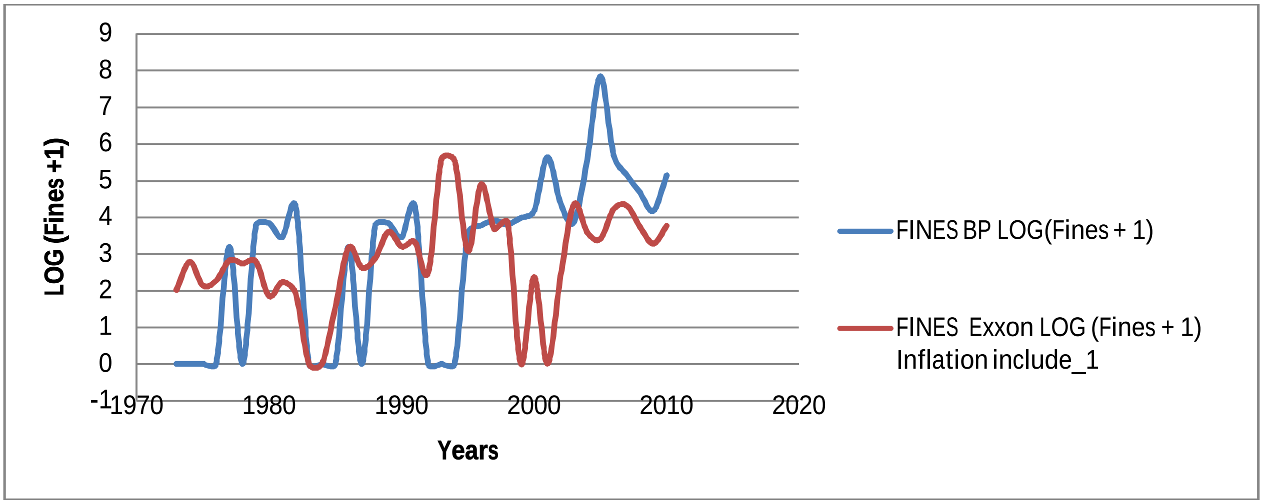

Figure 15 represent the time sequence plot of *LOG (Fines+1)*. This logarithm function had been used to compare in the same graph fines at BP and at Exxon from 1973 to 2011.Fines at BP are above fines found at Exxon for the period investigated.

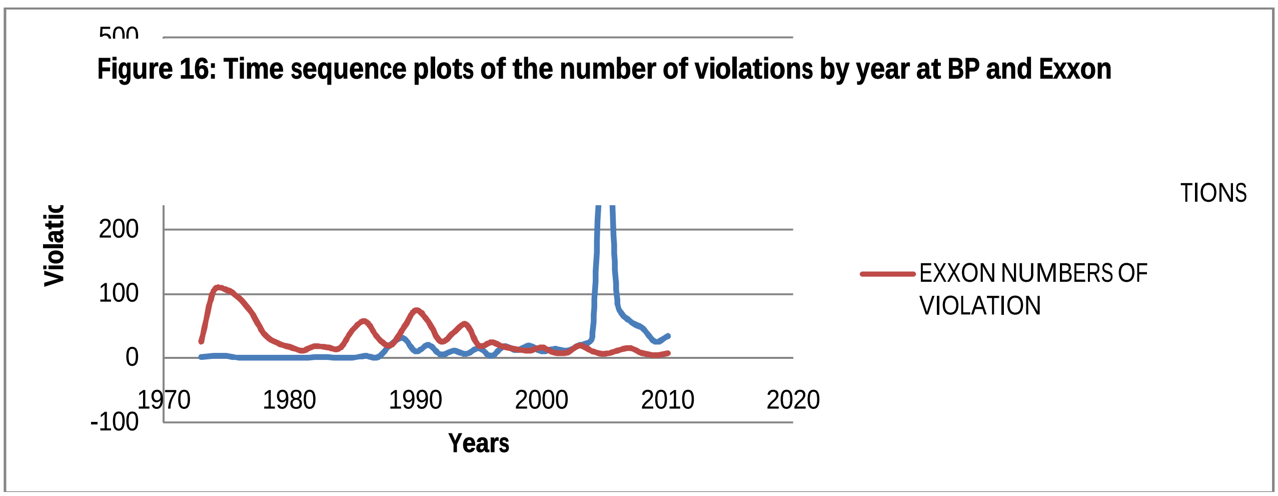

Figure 16: Time sequence plots of the number of violations by year at BP and Exxon

Figure 16 represent a time sequence plot of the number of violations at BP and Exxon from 1979 to 2010. Violations at Exxon were superior to violations at BP from 1973 to 1989. But after 2000 fines at Bp was highest compare to Exxon.

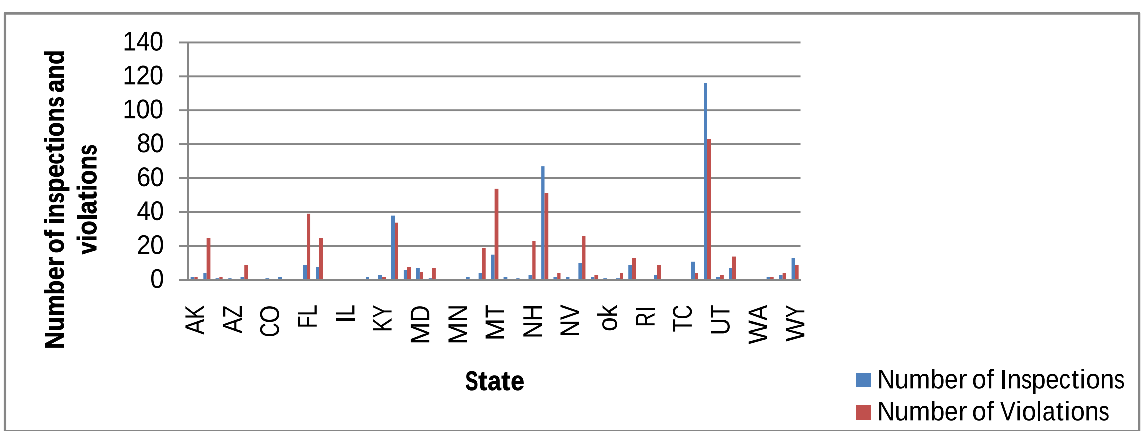

Figure 17: Number of Inspections and Violations By State At Exxon Before Exxon Valdez

Figure 17 represents the number of inspections as well as corresponding violations by state at Exxon before Valdez incident. We observed that the number of inspections was higher compare to the number of violations in Texas, New Jersey, and Louisiana. Conversely, the number of violations was higher compare to the number of inspections in Alabama, California, Florida, Georgia, Montana, and New York.

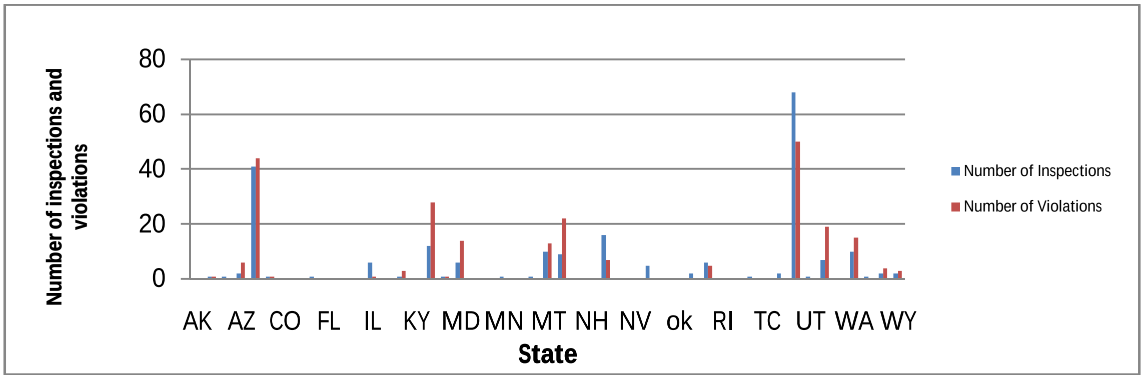

Figure 18: Inspection and violations at Exxon after Exxon Valdez

Figure 18 represent the number of inspections and corresponding violations at Exxon after Valdez incident. The number of inspections was higher compare to the number of violations in Texas, New Jersey, and Illinois. Conversely, the number of violations was higher compare to the number of inspections in Arizona, Louisiana, Maryland, Montana, and North Carolina.

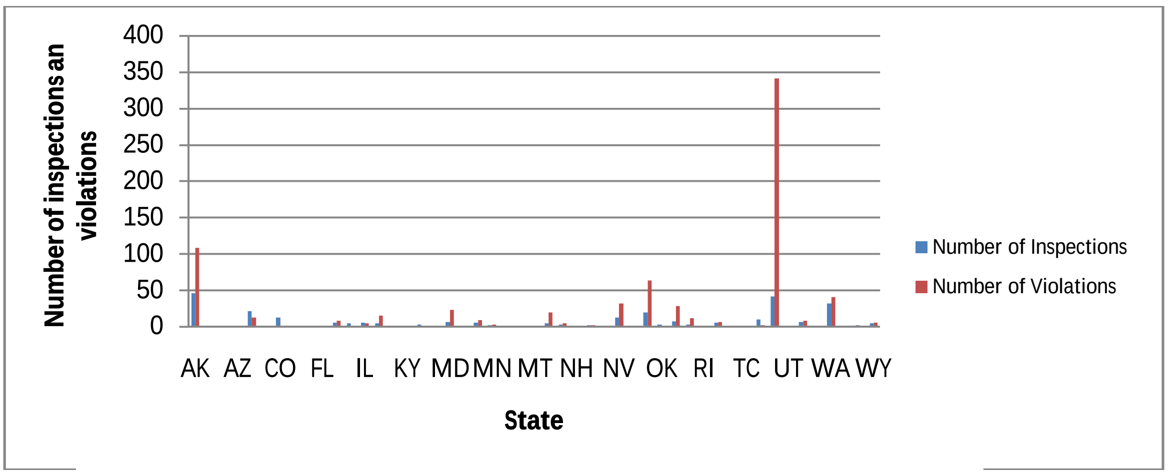

Figure 19: Inspections and violations by state at BP

Figure 19 represents the number of inspections and violations by state at BP from 1973 to 2010. The number of violations was higher compare to the number of inspections done by OSHA inspectors. A huge difference between the number of inspections and violations found was observed in Texas, Nevada, and Oklahoma.

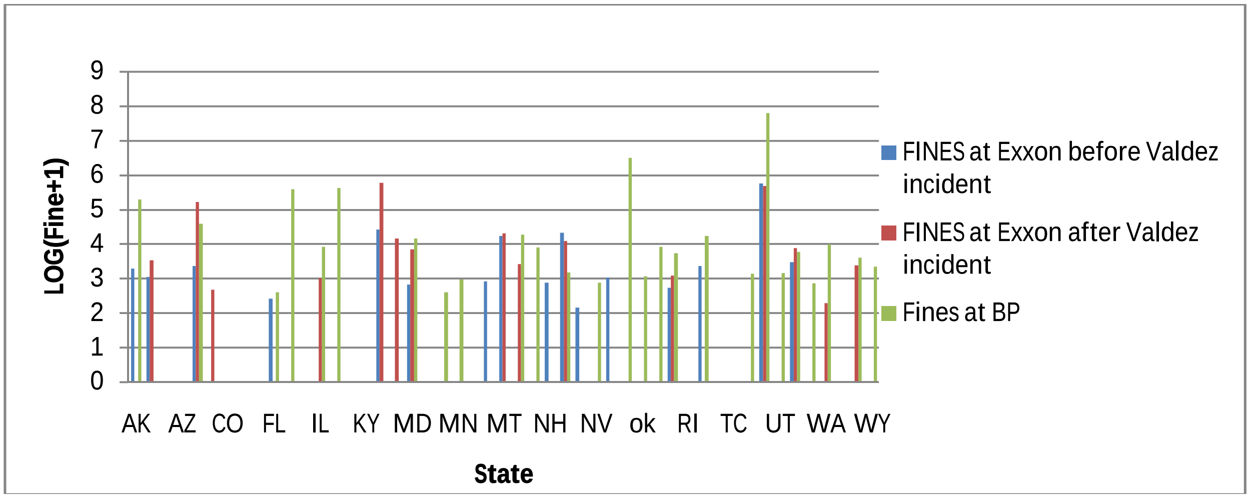

Figure 20: Fines by state before and after Exxon Valdez and at BP

Figure 20, represent Log (fines + 1) at Exxon before and after Valdez, and at BP. Put in the same graph, it is difficult to compare visually via histogram fines at Exxon and BP in other states and Texas. This is the raison why the logarithmic function was used to adjust the total fines by sates and by companies. In Alaska, fines at Exxon were inexistent after 1989 and fine at BP was greater than fine at Exxon after 1989. In California, fines at Exxon after 1989 were greater than fines at Exxon before 1989 and at BP. In Texas, fine at BP was greater than fine at Exxon after 1989, greater than fine at Exxon before 1989.

TABLE: Summary of fines and violations at Exxon and BP before and after they had experiment major accident.

	VIOLATIONS		FINES	
	EXXON	BP	EXXON	BP
BEFORE	686	934	106,817.1	70,523,027
MAJOR ACCIDENT				
AFTER	486	??????	1,271,742	??????

Regression Analysis

1. The regression model of the number of inspections and fines Before the Valdez accident in function of the number of years.

The regression equation is

Years = 1983 - 0.000067 EXXON Fines before Valdez + 0.076 EXXON inspections before Valdez - 0.158 EXXON Violations Before Valdez

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	1982.99	3.22	615.96	0.000
EXXON Fines Before Valdez	-0.0000669	0.0002215	-0.30	0.767
EXXON INSPECTION Before Valdez	0.0757	0.2483	0.30	0.765
EXXON Violations Before Valdez	-0.1584	0.2737	-0.58	0.573
S = 4.82711 R-Sq = 25.8% R-Sq(adj) = 8.6%				

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	105.09	35.03	1.50	0.260
Residual Error	13	302.91	23.30		
Total	16	408.00			

Base on the above multiple regression models, the slopes of fines and violations are negative while the slope of inspection is positive; this implied that, before Exxon Valdez, the number of violations and corresponding fines decreased while the number of inspections increased over the years.

2. *The regression model of Exxon fines, violations and frequency of inspection after the Valdez accident.*

In the following multiple regression model, the slopes of fines, inspections, and violations are negative. This implied that, after the Exxon Valdez, the number of violations, corresponding fines, and frequency of inspections have decreased after Exxon has experiment major incident.
The regression equation is:

Years = 2005 - 0.246 EXXON inspection - 0.000003 Fines after - 0.006 violations after Valdez

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	2005.43	1.44	1390.10	0.000
EXXON INSPECTION	-0.2460	0.1443	-1.70	0.107
FINES INFLATION INCLUDE AFTER Valvez	-0.00000305	0.00000961	-0.32	0.754
EXXON Violations AFTER Valvez	-0.0065	0.2148	-0.03	-0.976
S = 4.17326 R-Sq = 61.5% R-Sq(adj) = 54.8%				

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3.00	473.93	157.98	9.07	0.001
Residual Error	17.00	296.07	17.42		
Total	20	770.00			

3. *Linear regression of the number of violations at Exxon and at BP form 1973 to 2010*

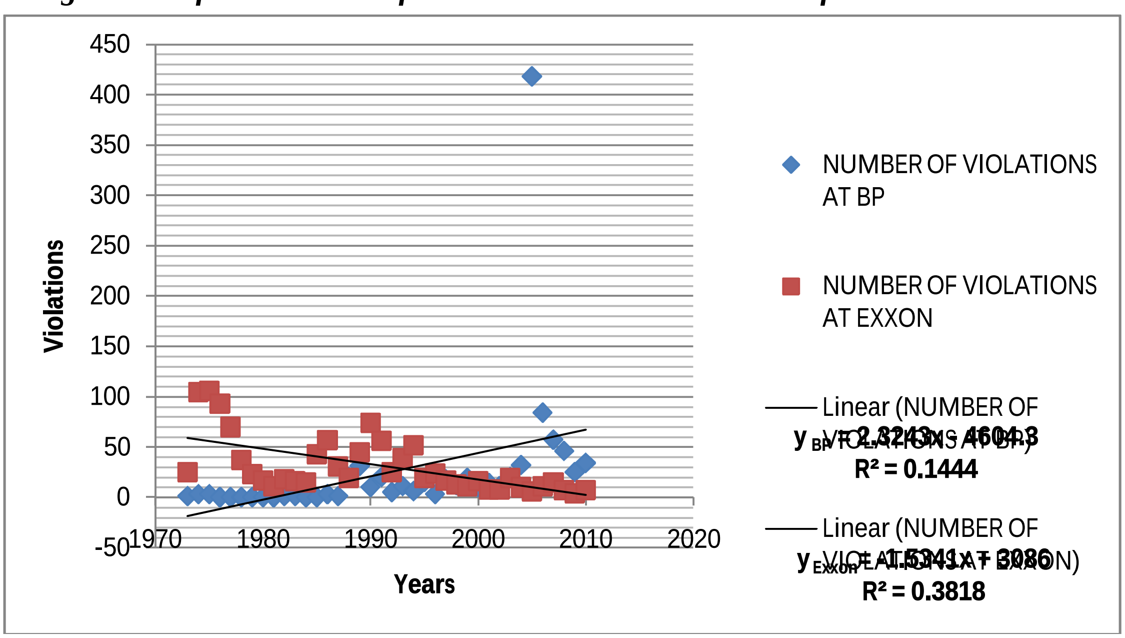

Figure 21: Linear regression of the number of violations at BP and Exxon from 1973-2010

Figure 21 is a linear regression of a number of violations at BP and Exxon from 1973 to 2010. Violations increased at BP over years; on the contrary to Exxon, violations decreased over years.
The following multiple regression equation compare the number of violations at Exxon at BP. It will be possible to predict the number of violations at BP based on the Exxon history for the future years.

Years = 1997 + 0.0405 NUMBER OF VIOLATIONS At BP - 0.225 NUMBER OF VIOLATIONS EXXON

4. Linear Regression of fines at BP versus fines Exxon

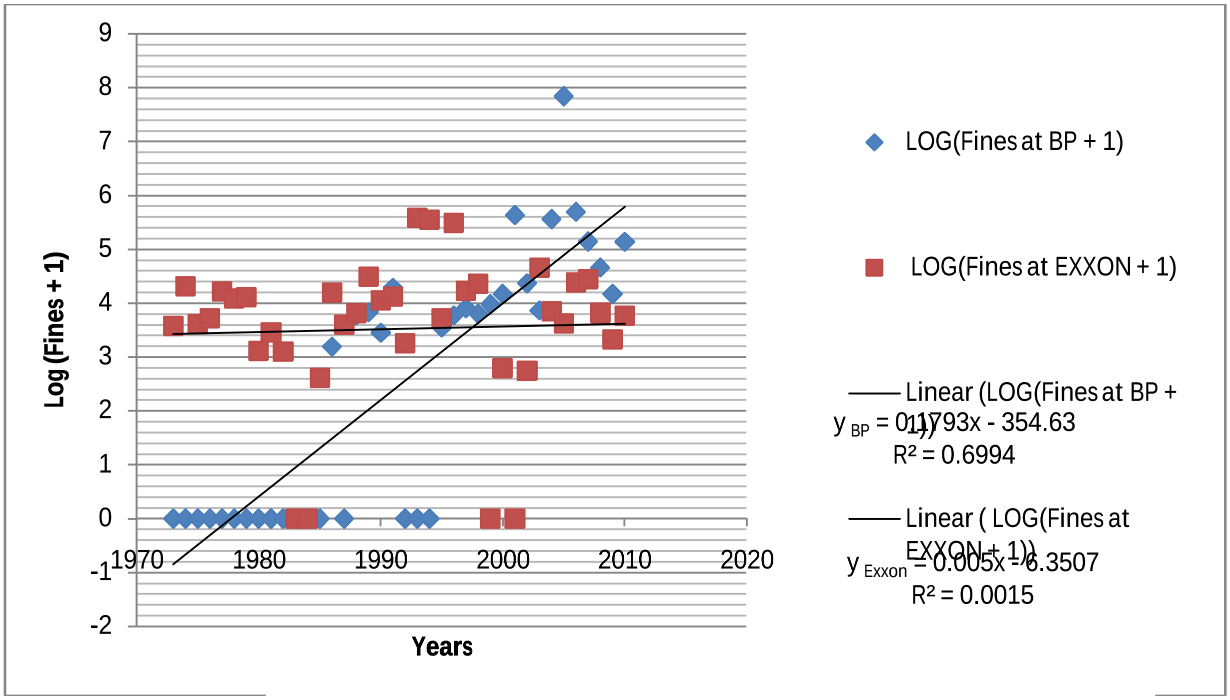

Figure 22: Linear regression of Log (fines + 1) at Exxon and BP

Figure 22 represent the linear regression of LOG (fines+1) at BP and Exxon. The slop of the regression equation representing of LOG (fine at Exxon + 1) is very low compare to the slope of the regression equation representing Log (fines at BP + 1) over the years. This difference of slops showed that, until 2010, fines at BP and Exxon had increased continuously, but the rising amplitude at BP was higher than the growing amplitude at Exxon.

The following multiple regression equation compare the LOG (fine at Exxon + 1) andthe LOG (fines at BP + 1) had been obtained.

The regression equation is:

Years = 1981 + 3.90 LOG (Fines at BP + 1) + 0.109 LOG (Fines at EXXON + 1)

*I*t will be possible to predict what will be the fine at BP based on the Exxon history for the future years.

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	1981.50	2.95	671.85	0.000
LOG(Fines at BP + 1)	3.8988	0.4323	9.02	0.000
LOG(Fines at EXXON + 1)	0.1093	0.7352	0.15	0.883
S = 6.26222 R-Sq = 70.0% R-Sq(adj) = 68.2%				

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2.00	3197.0	1598.5	40.76	0.000
Residual Error	35.00	1372.5	39.2		
Total	37.00	4569.5			

The non logarithmic linear regression was:

- ***Years = 1991 + 0.000000 BP Fines + 0.000012 EXXON Fines***
- ***EXXON Fines = 37184 - 0.00049 BP Fines***

5. Linear regression of violations at Exxon before and after Exxon Valdez incident of 1989

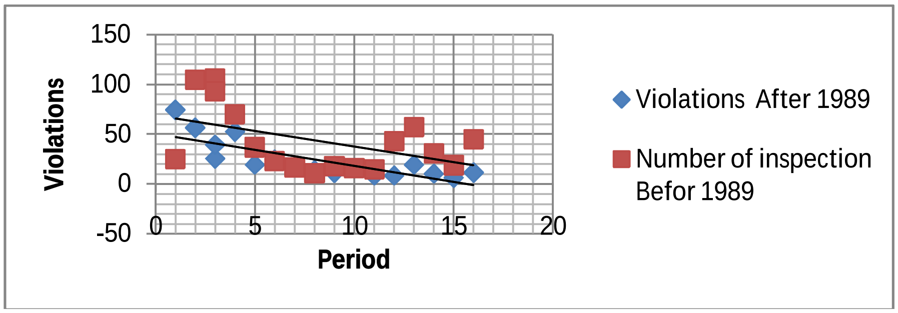

Figure 23: Linear regression of violations at Exxon before and after Exxon Valdez incident of 1980

Figure 23 represent the linear regression of violations at Exxon before and after the Exxon Valdez accident. Regression equations of violations over years are:

- Before Exxon Valdez : $y = -3.1264x + 68.563$ $R^2 = 0.2175$
- After Exxon Valdez : $y = -3.235x + 50.451$ $R^2 = 0.6232$

The slope of the regression equation is higher before Valdez accident than after. This confirms the evidence that: The decreasing of violations at Exxon after Exxon Valdez incident was lower than before.

Conclusion

Safety in general industry has improved in recent years in the United States of America. Despite these improvements, fatalities and catastrophic accidents have occurred in recent decades. This is the case of the BP Gulf of Mexico oil spill (2010), Bayer Crop Science pesticide waste tank explosion at West Virginia in 2008, BP Texas City refinery explosion 2005, and Exxon Valdez oil spill in 1989; the list is not exhaustive.

This study addresses the issue of safety in the petroleum industry and how safety culture can potentially influence the state of health and safety systems of different companies. It includes a comparison of the safety cultures of two large oil companies before and after they experienced major incidents utilizing integrate management information system (IMIS) data base from Occupational Safety and Health Administration (OSHA) website; the two major incidents are the Exxon Valdez incident of 1989 and the British Petroleum (BP) -Gulf of Mexico oil spill of 2010.

The results obtained from this study are consistent. A number of conclusions are made:

- Increasing OSHA inspections at Exxon had mitigated the number of safety violations and enhanced its safety culture.
- More violations were observed at BP before the BP oil spill than at Exxon. This is evidence that the safety culture system in its entirety at BP was inferior to the safety culture inherent at Exxon.
- Standards related to process safety management of highly hazardous chemicals and general equipment were the top two violations observed at BP and Exxon.
- The safety culture change that Exxon went through as a result of their incident will be replicated at BP.
- It was hypothesized that the number of safety violations at BP after the Deep Water Horizon in 2010 will decrease as observed at Exxon after Valdez incident.

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