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Rules Written in Blood: A Case Study of Risk Management in the Oil and Gas Industry

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ABSTRACT

Purpose: The study aims to investigate how and when the oil and gas industry adopts industry best practices and enhanced standards addressing process safety and operational integrity after catastrophic events.

Design/Methodology/Approach: We reviewed the literature available for disastrous incidents that shaped the oil and gas industry with a special reference to three distinct catastrophic events: Piper Alpha (1988), Deepwater Horizon (2010) and Ku-Maloob-Zapp (KUMAZA) (2021). Three primary case studies were evaluated to understand the cycle of creation and adoption of industrial standards meant to address risk management related to process safety and operational integrity in the industry.

Findings: We have proposed an adoption cycle for how the industry reacts to catastrophic events, with respect to the adoption of best practices, and creation of enhanced standards, to address the root causes of these events. System 1 thinking dominated initial reactions to each catastrophic event, through the integration of existing standards. System 2 thinking drives the formulation of enhanced standards which more thoroughly deal with additional factors which contributed to compelling events.

Research Limitation: Future research may explore the nuances related to the timeline for adoption of industry best practices once a standard is published by API, ISO, or another SME. These nuances could include different organizational profiles for companies adopting a standard.

Managerial Implications: This study offered insights intorisk management as applied to process safety in oil and gas operations. There exists a lag between the creation of industry best practices through the publication of standards, and the adoption of these practices.

Originality/Value: Future researchers may research and generalize findings beyond the current parameters of this study.

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Overview

The oil and gas industry has been marred by catastrophic events throughout its history. These events have changed the way the industry approaches risk and makes decisions (Acheampong et al., 2021). After these tragic events, governments, companies, and third parties have conducted extensive post-incident investigations which have led to the evolution of industry best practices and publication of enhanced standards to address root causes (Acheampong et al., 2021). Essentially, these standards are rules written in the blood of those casualties resulting from a catastrophic event. Through the analysis of key catastrophic events in the modern history of the oilfield, a trend emerges around the creation of industry best practices and the lag-time for the application of these enhanced standards as risk control measures at the wellsite. By breaking down this implementation gap, and comparing and contrasting catastrophic events and the industry response, it can be concluded that this lag-time is less than ideal. Therefore, we conclude that the reduction in this lag-time is paramount to drive further continuous improvement in process safety and enhanced operational integrity for oil and gas operations.

Introduction

The nature of exploration, development, and production of oil and natural gas involves hazards that, if left uncontrolled, have a high potential to result in undesired catastrophic outcomes Tabibzadeh & Meshkati, (2014) that can result in loss of life (Woolfson & Beck, 2000). Therefore, it is necessary for organizations operating in the oil and gas industry to have robust processes for risk management and decision making adequately address risks related to process safety and operational integrity Bryden et al., (2018), in oil and gas operations.

This paper analyzes the literature on catastrophic events that shaped the exploration and production of oil and gas and how the industry has adopted best practices regarding operational procedures and risk management into standards that drive decision-making and control measures onsite. We shall investigate the relationship between decision-making and risk management, establish a timeline for the incorporation of best practices, and analyze the adoption of enhanced subject matter expert (SME) standards after key catastrophic events within the oil and gas industry.

This analysis should be of value to organizations operating in the oil and gas industry for enhancing the understanding of decision-making in association with risk management, including the efficiency of best practice adoption in the form of SME standards to address risk management in process safety and operational integrity for oil and gas operations. The primary question driving our analysis, how and when does the oil and gas indus-try adopt industry best practices and enhanced standards addressing process safety and operational integrity after catastrophic events? Subsequent questions include:

- How have catastrophic events shaped risk management and decision-making in the oil and gas industry?
- What are the factors contributing to the adoption of best practices through the application of SME standards into risk management and decision-making onsite?
- How do industry best practices and SME standards impact process safety and operational integrity in the oil and gas industry?

Methodology

In order to address the above questions, we will first review the historical data of safety performance in the oil and gas industry to establish what we believe is a general trend. While available data for safety metrics indicate improvement in performance outcomes in the oil and gas industryin the modern era (Figure 1), what is not as clear is the distinct reasons why the data have improved. Since 1985, the number of *annual fatalities per million-hour worked* has decreased from the high point in 1986 with 18, decreasing to under four each year after 2007 as shown below in Figure 1 (IOGP, 2021).

While the data illustrated in Figure 1 is a clear indicator that outcomes related to process safety and operational integrity in the oil and gas industry are improving, undesired catastrophic events involving loss of life are still occurring in the industry today. To analyze whether this relates to the adoption of industry best practices and SME standards, we will outline the literature available for previous disastrous incidents that shaped the industry with a focus on three distinct catastrophic events: Piper Alpha, (1988), Deepwater Horizon, (2010). These

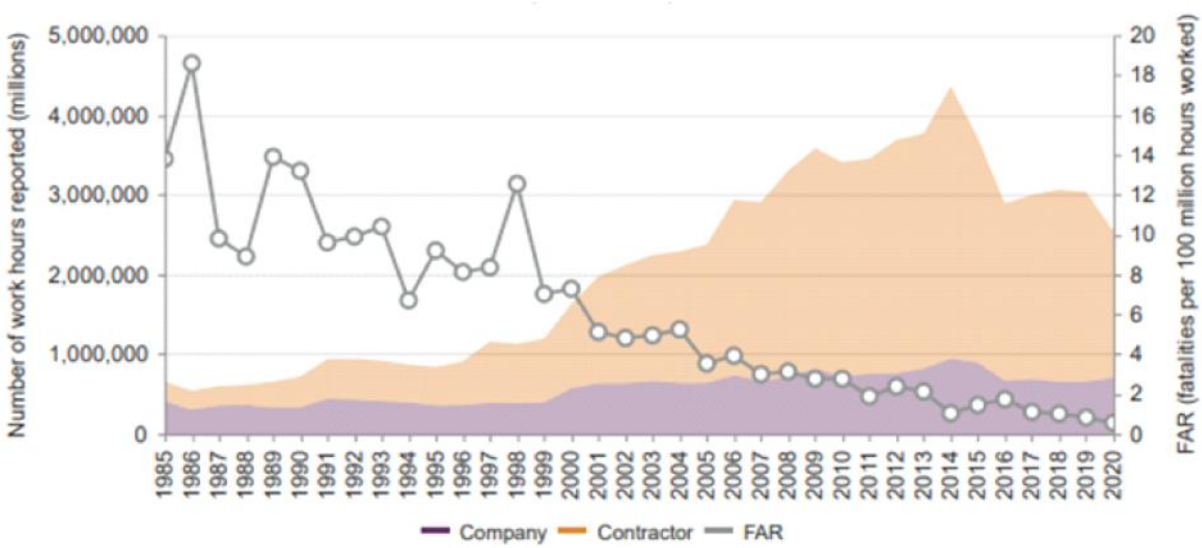

Figure 1: Reported Work Hours and Fatal Accident Rate 1985-2020

three primary case studies will be evaluated to understand the cycle of creation and adoption of industrial standards meant to address risk management related to process safety and operational integrity in the oil and gas industry (Figure 2). This cycle represents the process by which the oil and gas industry reacts to catastrophic events, adopts existing risk management best practices, and create enhanced standards for future application.

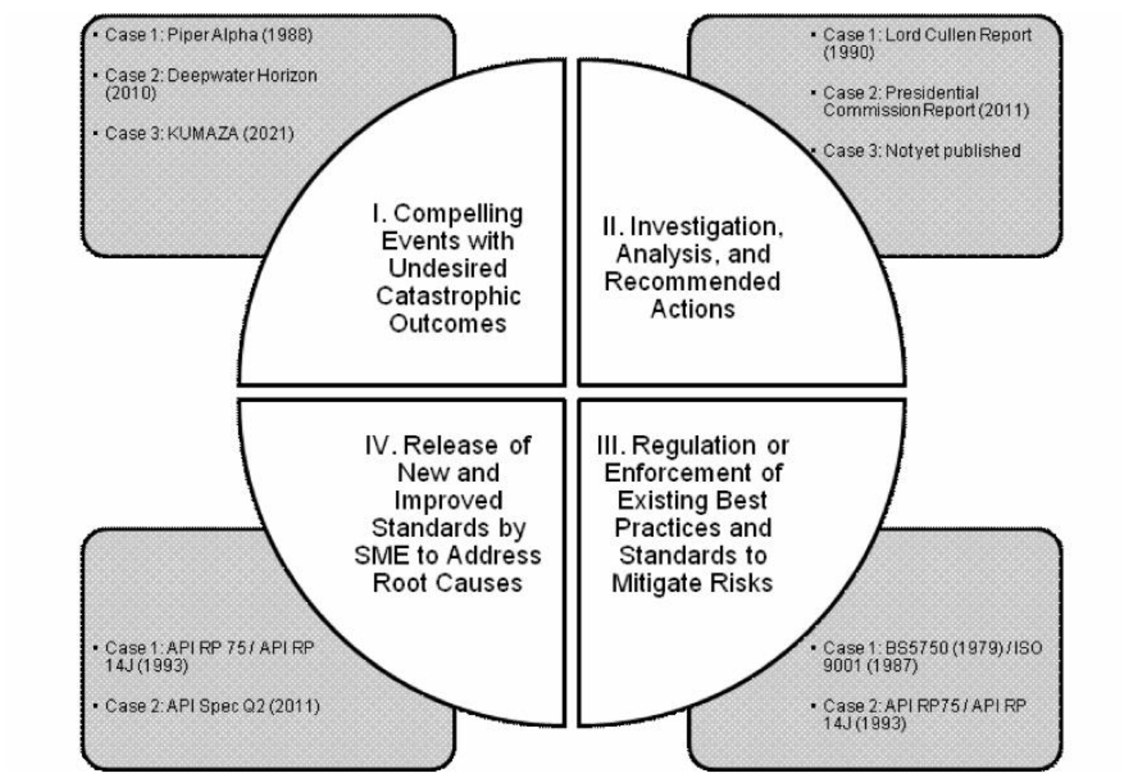

Figure 2: Proposed Cycle of Adoption of Standards addressing Risk Management in the Oil and Gas Industry

The first case study is the Piper Alpha disaster of 1988 and subsequent response by industry. We believe this event helped inform the regulatory environment between 1988 and 2010. The second case study is the Deepwater Horizon disaster of 2010 which we feel informed regulation between 2010 and 2021. This leads us to the third and fourth events that have occurred in 2021: The two recent KUMAZA events.

These case studies are further dissected into four distinct portions of the adoption cycle (Figure 2): I) Compelling Events with Undesired Catastrophic Outcomes II) Investigation, Analysis, and Recommended Actions III) Regulation or Enforcement of Existing Standards to Mitigate Risks IV) Release of New and Improved Standards by SMEs to Address Root Causes. As illustrated in Figure 2, the analysis of Case 3 will be limited only to I) and II), as at the time of publishing no investigation report is available for the recent KUMAZA incident.

For the review, we will consider the incorporation of industry best practices in the form of the adoption of the following SME standards into risk management and decision-making onsite. We will place these standards within the timeline of our analysis which is further furcated by the previously described disasters.

I. ISO 9000 - Quality systems. Guide to quality management and quality systems elements for services (First published in 1987). Starting in the 1980s there was a significant shift towards quality systems in the industry. The International Standard ISO 9000, European Standard EN 29000, and British Standard BS 5750 were developed in near parallel to set standards on quality management and assurance (D J Pratt, 1995). ISO 9000 was not specific to any particular industry or company size and could be seen as the baseline for quality with regards to satisfying customers and meeting regulatory requirements (ASQ, 2021a) (ASQ, 2021b) ISO 9000 is both a collection of standards and individual standard by itself.

II. ISO 9001 - Quality management systems – Requirements (First edition released 1987). ISO9001 focuses on the requirements necessary to formulate a quality management system. These requirements are necessary when an organization needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory/regulatory requirements and the organization aims to enhance customer satisfaction through this system (ASQ, 2021b). We will focus on ISO 9000 as a collection of standards and ISO 9001 as the individual standard.

III. API RP 75 - Safety and Environmental Management System for Offshore Operations and Assets (First edition released 1993). Focusing more on the oil and gas industry, API Recommendations Practice (RP) 75 is similar to ISO 9000 by setting standards to develop a quality management program but with a shifted focus toward the safety and environmental protection during offshore oil and gas operations, as well as operations where sulfur is involved (API, 2004). The overall goal of API RP 75 is to develop a Safety and Environmental Management System (SEMS) to highlight significant safety hazards and potential environmental impacts where the operators have control over and can be expected to have influence (API, 2004). There are six steps to developing a successful SEMP (API, 2004):

i. Safety and environmental policy
ii. Planning
iii. Implementation and operation
iv. Verification and corrective action
v. Management review
vi. Continual improvement

IV. API RP 14J - Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities (First edition released 1993). In the wake of the Piper Alpha, (1988) disaster API RP 14J was developed in 1993. The standard outlines minimum requirements and guidelines for the arrangement and design of production facilities on open offshore platforms. According to API RP 14J, at minimum these guidelines should be applied to the following situations (API, 2001):

i. Spatial limitations that may cause potential ignition sources being installed in or near production equipment.
ii. Spatial limitations that may result in quarters being installed near production equipment,

pipeline/flow line risers, fuel storage tanks, or other major fuel sources.

iii. The inherent fire hazard presented by the release of flammable liquids or vapors, whether during normal operations or as a result of any unusual or abnormal condition.

iv. High-temperature and high-pressure fluids, hot surfaces, and rotating equipment located in or near operating areas.

v. The handling of hydrocarbons over water.

vi. Large inventories of hydrocarbons from wells/ reservoirs and pipelines connected to or crossing a producing platform.

vii. Storage and handling of hazardous chemicals.

viii. Potential H2S releases.

V. API Spec Q2 - Quality Management System Requirements for Service Supply Organizations for the Petroleum and Natural Gas Industries (First edition released 2011). API Spec Q2 was developed to reduce risk and improve the quality of upstream services (Straessle, 2014). The creation of API Spec Q2 began in early 2010; however, the BP Deepwater Horizon disasterof 2010 accelerated development and the specifications were subsequently released in December 2011. API Spec Q2 identifies and standardizes the expected performance of upstream services. API Spec Q2 certification involves drafting procedures ensuring personnel competency, risk assessment, contingency planning, and numerous other quality management system (Straessle, 2014). Note that for **API Spec Q2 1st Edition –** All certificates will be withdrawn on January 14th, 2023.

VI. API Spec Q2 2nd Edition (anticipated to be released in 2022) – The most current set of industry controls comes courtesy of the APIQR Program, in which the original registrants from the 2011 API Spec Q2 are required to transition into an enhanced "quality management system that controls their operational processes, provides consistent results, manages change effectively, allows for continuous improvement, reduces operational downtime, and increases customer satisfaction" (APIQR, 2021). Auditors work with certificate holders to ensure collaboration during the transition period, prior to a formal audit, to confirm compliance of transition requirements from APIQ2 to APIQR. Through the application of this enhanced standard for Quality Management Systems (QMS), APIQR Program Licensees, Registrants, and others are tasked with specific activities for the exploration and production of hydrocarbons, in contrast to typical industry derived and written activities to take the place of external regulation. Including the activities of non-integrated service providers, APIQR allows standards to be applied to the process controls ranging from equipment repair to inspection activities and, most importantly, well construction, intervention, and abandonment as these activities have, to date, lacked best practices. Full system audits for compliance with the APIQR program shall begin January 14th, 2022, after which time corrective actions and nonconformance will be assessed according to the outlined QMS framework.

Introduction to the Case Studies

On July 6th, 1988, at 9:55 pm, a fire erupted on the Piper Alpha production platform, operated by Occidental Petroleum in the UK North Sea. Later reports would show the event was, among other contributing factors, the result of a gas leak (Cullen, 1990). Sadly, the fire and the subsequent explosions would claim the lives of 167 men working on the platform.

Thirty-three years later on July 2nd, 2021 at 5:15 am, flames erupted on the surface of the Gulf of Mexico just west of the Yucatan peninsula. The fire was adjacent to a crude oil platform operated by the Mexican state oil company, Petróleos Mexicanos (PEMEX). Production was out of the KUMAZA offshore oilfield complex, Mexico's most important developmental area (Barrera & Parraga, 2021). The fire began in an underwater pipeline that connects to the platform. The initial statement from PEMEX pointed to a malfunction of the turbomachinery on the active production following an electrical storm and heavy rains (Barrera, Parraga, 2021). Unfortunately, less than two months later, on August 23rd, 2021, another fire occurred in the KUMAZA field, completely engulfing the E-Ku-A2 production platform in flames, tragically resulting in the loss of life for seven workers.

Although the outcome of the second fire in KUMAZA was tragic, when compared to the Piper

Alpha, the decision-making process and results were significantly different. To understand why this is, the circumstances and actions taken around the events must be examined in detail. The variables influencing the outcomes must be determined, compared, and contrasted.

Based on the outcome of Piper Alpha and the subsequent investigation (Cullen, 1990) control measures relative to risk and decision-making, targeted to improve process safety and enhance operational integrity, were introduced and published by SMEs. Unfortunately, several of these standards were not implemented throughout the industry until after 2010 and the Deepwater Horizon catastrophe, when 11 people lost their lives when the drilling rig exploded at the Macondowell site in the U.S. Gulf of Mexico (National Commission, 2011).

After the Deepwater Horizon event, the existing best practices related to process safety and operational integrity, which were created after Piper Alpha, were adopted. In addition to these practices, SMEs published enhanced standards (Woolfson, 2013). In this paper, we will seek to establish if it was the adoption of these enhanced standards onsite at KUMAZA that led to a different outcome despite the similarities in circumstance with the Piper Alpha events. We will also explore if the second fire in the KUMAZA field is a nexus event for the next cycle of best practice adoption and standard creation for the industry.

Case 1 – Piper Alpha (1988-2010)

I. The Event

The fire that took place on the Piper Alpha platform on July 6th, 1988 was a catastrophe that sadly caused the deaths of 167 men. Further to the tragic loss of life, the estimated financial loss was equivalent to five billion US dollars in 2018. (Macleod, 2018). Only a week later,the UK launched a public inquiry assembled and headed by Lord Cullen, an appointed Senator of the College of Justice and judge of the High Court of Justiciary and Court of Session (Offshore Energy, 2013).

II. Investigation and Analysis

Cullen's primary duty as a senior Scottish Judge was to investigate the causes and underlying factors of the Piper Alpha accident. The extensive investigation resulted in the publication of the 800-page Cullen Enquiry Report on November 12, 1990. The Cullen Enquiry Report concluded that the first explosion was due to the release of a small amount of methane gas through an unsecured blind flange (Macleod, 2018). The removal of the pressure safety relief valve, a primary control measure for process safety, after routine maintenance triggered the chaotic fires and explosions whicheventually consumed the rig (Cullen, 1990). In addition tothe technical aspects of the disaster highlighted in the Cullen report, perhaps the most revealing issue was the management's widespread disregard of process safety and operational integrity exemplified by cutbacks on maintenance in response to the oil turndown in the 1980s. The lack of safety reporting culture from the workforce, coupled with a lack of focus on risk control and mitigation, contributed to the catastrophic loss of life (Cullen, 1990).

While the Cullen report centered most of its attention on the culture and practices of Piper Alphas operator, the US-based oil and gas company Occidental Petroleum, one of the most glaring insights was that what happened at Piper Alpha could have happened on any North Sea platform at the time. Contributing factors to this included resistance to union oversight on offshore rigs and deficiencies in oversight of the UK Department of Energy (DOE), which effectively created a "regulatory zone of exclusion" for operators in the North Sea (Woolfson & Beck, 2004; Hansard, 1980). This environment was not conducive for voluntary adoption of the industry standards aimed to promote operational integrity at the expense of efficiency. Unfortunately, in this environment, the UK DOE was limited in its ability to effectively enforce and mitigate the critical actions required onsite to prevent undesired outcomes relative to process safety.

III. Safety Standards and Risk Mitigation

When oil was discovered in the North Sea in 1969, Britain did not have the resources or capital to extract these hydrocarbons. This required Britain to form an alliance with the US, which invoked the adoption ofthe US production regime, centered around the fastest possible extraction with limited regulatory oversite. This production style was hailed by both the Labor and Conservative parties, at the time which Woolfson & Beck (2004) coined the slogan "the political economy of speed" (Whyte, 2018). It would take four years for UK regulatory industries to catch up with the newly created industry and install basic safety regulations with the Minerals Working Act and the Health and Safety Work Act of 1974 (The National Archives, 1992). During this period, workforce safety fell under the responsibility of the Petroleum Engineering Division located within the UK DOE. This particular bureaucratic arrangement enabled the offshore industry to effectively resist the application of key regu-lations and safety standards (Lindoe, 2013; Woolfson & Beck, 2004).

In 1987 International Standards Organization published ISO 9000 detailing a guide to quality management compliance. As outlined previously in this paper, the ISO 9000 framework set forth a system of overall management responsibility and defined authority (Bennet, 1995). However, at the time, the management structure for operations on Piper Alpha did not meet the supported criteria outlined by the European Economic Community (Bennett, 1995). Unfortunately, this lack of control in the management system limited the application of the key safety principles outlined by ISO 9000 (Wilkinson, 2014). The management team of Piper Alpha instead was resistant to independent audits and agency monitoring. This created an organizational culture in which management placed greater value on ignoring risk controls, as opposed to taking the necessary action to prevent accidents, as Woolfson & Beck (2004) describes as an "institutionalized tolerance of noncompliance" (Woolfson & Beck, 2004).

Lord Cullen's Enquiry concluded that the offshore industry strategies from 1970-1988 to avoid unions involvement in their operations as a sign of managements tendency to use command and control tactics to dissuade employees from challenging non-unionized structures, (Cullen, 1990). These tactics were met with the threat of work stoppage by platform employees, which could have considerable on production during summer maintenance periods (Thom, 2011). To sidestep potential losses incurred during a strike, company and union officials created "hook up agreements" to provide frameworks for collective bargaining in which the parties agreed to not halt production. While this effectively curtailed the risk of production disruption, this came with significant downside risk, especially for the employees. As a result, employees lacked job security while management was not effectively incentivized to promote safety culture, including safety reporting, leading up until the catastrophe. Therefore, platform workers were limited in their ability to voice safety noncompliance or speak to union representatives about unsafe offshore installation practices, and Lord Cullen found that this culture was a significant contributing factor to the tragedy.

IV. Addressing the Root Causes

Lord Cullen recommended three primary changes after Piper Alpha: The creation of the Formal Safety Assessment (FSA) to enhance risk control and mitigation, improved regulations to promote workforce safety involvement onsite, and the elimination of maintenance deferral for the sake of increased production (Preben Lindoe, 2013).

The Piper Alpha disaster provided both the public and private sectors an opportunity to gain a true perspective on the organizational culture of the offshore industry during the late 1980s and early 1990s. Even though ISO 9000 provided members of the European Economic Community standards to safely operate within, at the time of the accident it was found that key safety initiatives were ignored onsite. Quality assurance concepts, coupled with active monitoring from safety management systems by the newly formed UK Health, Safety, and Environment (HSE) department within the UK DOE, stressed the importance of adhering to sensible policies that can be planned and implemented (Wilkinson, 2014). The performance of these plans was to be audited by independent third parties to validate compliance with ISO 9000. These audits were meant to review the overall management system controls, from senior management level down to the application of risk control measures onsite (Wilkinson, 2014).

The adoption of ISO 9001 in 1994 placed heavier emphasis on the implementation and continuation of quality management and critical control measures for product design, with an enhanced definition of management responsibilities. In the years following Piper Alpha, North Sea oil and gas operations were placed in the public spotlight, whichprovided an impetus for operators to promote enhanced process safety and operational integrity performance. Fortunately, since the Piper Alpha disaster, there has not been any similar catastrophic event in the UK North Sea. Further, in 1993 API released Recommended Practice 75 and SEMS to address operational integrity and 14 J to address process safety root causes identified in the Lord Cullen report. Unfortunately, these standards were not widely adopted until 17 years later after Deepwater Horizon.

Case 2 – Deepwater Horizon (2010-2021)

I. The Event

The Macondo #1 well was an exploratory well designed to evaluate Middle Miocene oil and gas-bearing sand intervals approximately nineteen thousand feet below the surface of the Gulf of Mexico (BP, 2010). The well was designed to be temporarily abandoned after drilling, allowing for the option to be completed at a later date if commercial quantities of hydrocarbons were discovered. It was drilled in Mississippi Canyon Block 252, acquired by lease from the Minerals Management Service (MMS) on March 19th, 2008 (BP, 2010). Drilling began via the Marianas semi-submersible drilling rig, operated by Transocean, on October 6th. On November 8th Hurricane Ida forced the Marianas to secure the well and evacuate the location. The Marianas sustained hurricane damage and was brought in for repairs. The Deepwater Horizon took over drilling operations on the Macondo well on February 6th, 2010. The Deepwater Horizon was also a semi-submersible drilling rig, commissioned in 2001. It was also owned and operated by Transocean and had been contracted to BP for nine years leading up to the disaster (BP, 2010).

Not uncommon in exploratory wells in the Gulf of Mexico, the Macondo well encounter numerous, relatively minor, incidents that resulted in changes to the original well design but were all controlled effectively. Drilling operations concluded on April 9th, 2010, where a total depth of 18,360 feet was reached. After reaching the final depth, the next five days were spent evaluating zones of interest using well logging equipment. The well was then circulated to ensure that there was no gas entering the mud, a sign that the underlying intervals were isolated from the surface. On April 16th the Macondo well was approved for temporary abandonment by the MMS, (BP, 2010).

On the evening of April 20th, 2010, a loss of well control on the Macondo #1 well during the final stages of abandonment resulted in natural gas breaching the wellbore which was previously isolated from the producing formation. The gas displaced the fluid column in the well to the surface, came up to the rig floor, and subsequently ignited. The extreme pressure from the formation resulted in a blowout visible from some 40 miles of open waters. The ignition and ensuing explosion caused the Deepwater Horizon rig to become fully consumed by fire for thirty-six hours before sinking to the seafloor (National Commission, 2011). Tragically, 11 people lost their lives in the fire. Further to the tragic loss of life, an estimated 4,900,000 barrels of oil would be released during the ensuing effort to contain the blowout, resulting in untold ecological, environmental, and financial damages.

II. Investigation and Analysis

On May 22nd, 2010, the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling was commissioned by the President of the U.S. to provide a thorough analysis and impartial judgment (National Commission, 2011). The Commission consisted of seven bi-partisan members who were charged with determining the root causes of the event and recommend corrective actions to improve process safety and enhance operational integrity for offshore energy production. The commission took six months to complete its investigation and in January 2011 reported its findings in a 398-page report to the President entitled “Deep Water: The Gulf Oil

Disaster and the Future of Offshore Drilling.

The findings of the report included the following statements (National Commission, 2011):

- "The explosive loss of the Macondo well could have been prevented."
- "The immediate causes of the Macondo well blowout can be traced to a series of identifiable mistakes … that reveal such systematic failures in risk management that they place in doubt the safety culture of the entire industry."
- "Because regulatory oversight alone will not be sufficient to ensure adequate safety, the oil and gas industry will need to take its own, unilateral steps to increase dramatically safety throughout the industry, including self-policing mechanisms that supplement governmental enforcement."

Despite Transocean and BP both having procedures in place that guided the risk management process, collaboration on process safety requirements or concerns was not adequately addressed. These issues were highlighted by a previous incident prior to the blowout when, on March 8th, 2010, the rig crew on site were unable to recognize a similar well-control issue. Unfortunately, at that time there was no response by any of the three parties' operational procedure, training, nor well control response. The corrective action from the previous event was slow to be applied and Transocean was still wrapping up an investigation and management audit when the catastrophic event occurred on April 20th, 2010 (National Commission, 2011).

By the time things went critical on the Deepwater Horizon on April 20th, 2010, two principals from Transocean and two from BP were on the rig finalizing the investigation from the prior incident. During this time the management team was noted to be intentionally avoiding the third-party contractor mudloggers that missed the prompt detection of a potentially explosive gas kick the month before. The team investigating affairs on the rig were intent on tackling risk mitigation from the ever-present occupational safety concerns of slips, trips and falls, life vests, exposures, and worker hazards, but were so myopic about the personal safety matters, the focus was missing from the process safety matters that were progressing. Specifically, in the incorrect application of temporary abandonment following a misinterpreted negative pressure test of Macondo #1 before cementing, a contributing factor to the blowout (National Commission, 2011).

By April 20th, 2010, the Macondo #1 well was fifty-eight million dollars over budget. Therefore, the intent of the management walk around was largely to highlight why the operation was over-budget. This is supported by the fact that the safety team made no official audit of the third-party contractor's mud shack, nor was there any commentary on the decision to plug the well with cement until further exploitation became possible. The inspectors also missed the opportunity to verify that the blowout preventer was properly working. Unfortunately, without this data, it would become impossible to determine if the blowout preventer may have functioned properly since it was destroyed as the rig eventually sunk into the Gulf of Mexico (National Commission, 2011).

During the management walk around at the wellsite that served as a proxy for a real investigation into the March 8th incident, the mud engineers were not approached by the investigators. Mud engineering is a role that demands a significant amount of attention, analysis, evaluation. It also needs effective communication amongst all interdisciplinary members of the drilling operations. However, the methodology for risk management in fluid engineering and the subsequent impact on operational integrity was left unverified by both parties' VIP investigators. "In subsequent testimony, the auditors explained that they did not look into operations at the mud shack so as not to give the impression that the qualifications and professionalism of the chief mud engineer and his crew were being questioned" (George Baker, 2011).

The possibility of industrial safety hotspots, such as the mud shack being willfully ignored following a for-cause investigation, were tied up by the time the entire rig was the victim of eight further systems failures when the Macondo #1 well blowout event occurred at 9:50 pm on April 20, 2010.

In the post-accident investigation following the full loss of well control, little attention was paid to the measures that should have been set in place that could have prevented the extraordinary monetary and environmental costs of this well failure. Early kick detection is critical to maintaining well control, and detection failure was overlooked the day it failed on the Deepwater Horizon.

III. Safety Standards and Risk Mitigation

BP performed a pass/fail test in Houston to determine temporary abandonment of the well before running production casing and cementing. As a result of the test, they cut the drill plan 1,800 feet short of the intended measured depth .While this is at their discretion, the Houston-based engineers implemented a new procedure for temporary abandonment that was not approved by the MMS. The order of events is confused by the number of changes to the ad-hoc procedure called in by Houston. A second negative pressure test using a different procedure indicated to Don Vidrine, a BP middle manager on the rig, that no hydrocarbons were flowing or able to flow into the casing, to the riser pipe past the blowout preventer stack and into the solids control area where returns are processed and analyzed for the chemical and physical characteristics. Mr. Virdine was confused when he called back to Houston an hour before the untimely conflagration to describe the negative pressure test in more detail. Mark Hafle, a BP Houston-based engineer answered the phone. Hafle asked questions and agreed with Virdine on the operation's success, however no data from the rig's continuous electronic data recorder were verified by Houston to confirm success (National Commission, 2011).

The decision to abandon at 18,360' measured depth rather than the 20,200' measured depth was informed by the March incident in which well control was sub-critical, and a drill pipe became lodged, along with increasingly complicated pressure gradients experienced and expected going forward to the total depth (TD) originally planned. The mud shack crew missed another kick.To their credit, changing pressure gradients and anomalies are seen while using slick water, as was the fluid of choice at the time. Definitive findings while pressure testing can be overlooked at the cost of higher drilling efficiency, effects of formation damage, and reduction of fluid loss (BOEM, 2011).

The exploration and production of hydrocarbons offshore increases the risk involved, with the seafloor being five thousand feet below the semi-submersible drilling rig. Success in this particular operating environment relies more on the successful evaluation and management of risk through the use of standards and procedures developed from experience rather than the comfort of academic probabilistic analysis. With an increased risk to the environment, and less forgiving conditions for false interpretations, the industry has relied on a collaborative result of often experientially based developments in exploration and production.

Technical professionals have developed existing standards using vetted engineering practices and remain under current review since 1924 by the American Petroleum Institute (API, 2020). This set of industry best practices does not replace regulatory regimes to include enforcement but does allow for a consortium of safety concerned worksites, their decision-makers, and the protection of the general public as energy demands grow. API is accredited by ANSI, or the American National Standards Institute. Alternatively, the October 2010 lifting of the federal deepwater drilling ban enacted after the Macondo blowout, called on API for more refined standards on blowout preventer maintenance, safety certification, well design, and training of individuals involved in these practices.

V. Addressing the Root Causes

The Macondo catastrophe, and subsequent report to the United States President, led to API releasing enhanced best practices and creating new standards to address areas of specialty to increase training opportunities, preventative measures, and guidance for prevention and response to events. The goal was not only to avoid another federal drilling ban but to restore confidence in offshore operations.

API has taken model leadership post-Macondo by hosting panels and collaborating with government regulators to address the failure analyses revealed by the Presidential Oil Spill Commission. The industry panels convened around four topics intended to restore confidence in deepwater operations, and the government's ability to assess, then mitigate risk through its channels of regulation and enforcement. The targets for panels were subsea well control, containment, spill response, and operating procedures. The US Department of the Interior working alongside the recommendations from the Presidential Commission Report, sought relevant updates to regulatory frameworks and industrial safety.

Large producers want corporate standardization for its enhanced productivity metrics afforded by properly performing a task at its lowest possible risk for loss, routinely, with one set of revisable training curricula that can be distributed to remote locations simultaneously. Conflict of interest is avoided under the well-intended compilation of shared risk assessment and management knowledge that shares a developmental cost. API certification requires resources, and enforcement is limited to revocations, non-renewals, and suspensions until problem areas are brought into alignment with declared quality management systems planning. Until corrective action is taken, and reinstatements are offered, exams have been given, audits made, training provided, and procedures were rewritten, there can be real-world consequences for drilling off course.

Proactive engagement by API comes through the newest safety standards clearinghouse from 2011 with the Center for Offshore Safety developing a track record of industrial safety, concern for the environment, focus on risk management, and responding with operational integrity in the domain of API RP 75 and SEMS to improve process safety on the outer continental shelf (COS, 2021). Additionally, API launched Specification Q2 for the oil and gas service industry in 2011 to enhance operational integrity by addressing gaps in Quality Control identified in the Presidential Commission report (API, 2020).

Case 3 – KUMAZA (2021)

I. The Event

The final event analyzed in this review is a gas leak fire in the KUMAZA oil field off of the coast of Mexico in the Gulf of Mexico. According to a statement by the parent production company, Mexico's state-run oil company Petróleos Mexicanos (PEMEX), there was a leak in a 12-inch pneumatic pumping pipeline after an electrical storm caused the pneumatic pump turbocompressor to go out of operation for the production wells . The gas leaked from the pipeline to the surface and was ignited due to an electric shock. The firefighters fought the blaze for five hours before the flames were extinguished by closing the submarine valve and injecting nitrogen into the gas pipeline. Fortunately, no oil spilled and there was minimal environmental damage.

A 2017 review of the PEMEX's operations and governance outlined the progress that the company had made since Mexico's Energy Review of 2013 which opened the industry in Mexico to competition. The review discussed, among other topics, PEMEX's safety and risk management procedures since the reorganization of the company changed the structure from a decentralized to a centralized business model. The review also audited PEMEX's safety and risk management during operations (OECD, 2017). The review provided an assessment and recommendations and will be used to tie the evolution of the risk management and controls of PEMEX leading up to the KUMAZA disaster.

Unfortunately, less than two months later, on August 23rd, 2021, another fire occurred in the KUMAZA field, completely engulfing the E-Ku-A2 production platform in flames, tragically resulting in the loss of life for seven workers (The Maritime Executive, 2021). While at the time of publishing, little information regarding the event is available to the public at this time, it is apparent that the fire broke out while crews were performing maintenance work. The company's chief executive attributed the accident to the riskiness of the business and pointed out the frequency and severity of these events have been reduced (Martinez, 2021).

Discussion: Connection of Events

When comparing and contrasting these unfortunate events, a timeline emerges dictating the change in thought across the industry. This change in thought over time follows the same general pattern in both the Piper Alpha and Deepwater Horizon eras. As illustrated in Figure 4, this pattern includes inadequate safety protocols, the publishing of better practices and standards but with poor implementation, a catastrophic event, and then strict implementation of the enhanced standards.

The Piper Alpha disaster occurred in 1988 while offshore drilling in the North Sea was in its infancy. The first discovery of commercial oil occurred 19 years earlier in December of 1969 in the Ekofisk Field. At this time the mindset of the industry was in the exploration phase where it was all about drilling fast. The result of this mindset had led to numerous accidents and oil spreads throughout the region. With increased pressure to improve conditions, the earliest standards were developed in the United Kingdom. These standards were eventually implemented in the international standard, known as ISO 9000 in 1987. Although the standards were in place, adoption was low. The Piper Alpha disaster was an eye-opening moment for the industry and quickly changed how people and companies prioritized quality system management.

In the wake of the Piper Alpha disaster API RP 14J was developed and released in 1993. It directly acknowledges the operational mistakes that lead to the disaster. Although API RP 14J highlighted potentially mitigated operational risks, there was still additional risk associated with the competency and risk mitigation planning in the upstream sector. It was not until early 2010 the industry began addressing the risk through the development of API Spec Q2. As previously seen in the Piper Alpha case study, the adoption rate of these measures was minimal. This highly publicized event highlighted the decision-making process and inadequate contingency planning which eventually led to the unfortunate results of the oil rig explosion at Deepwater Horizon. This accelerated the development of API Spec Q2, which was then released in December of 2011. Again, it took a drastic event to quickly shift the mindset of the industry and force companies to implement the standards and regulations that were already being developed.

Since the Deepwater Horizon disaster, it may appear through the continuous improvement in safety metrics that the industry has begun to focus on quality management and prioritize safety over-production. However, if standard adoption is the indicator, it must be noted that even API Specification Q2 has not been adopted yet across the board in the oil and gas industry. Although PEMEX does not have a reputation for being the most reliable company in the industry, they have implemented several of these standards, including API 14 J (API, 2020). PEMEX also improved risk control measures following an initial Superior Audit Office's (ASF) evaluation in 2013, although ASF made additional recommendations for PEMEX to improve identification and assessment of

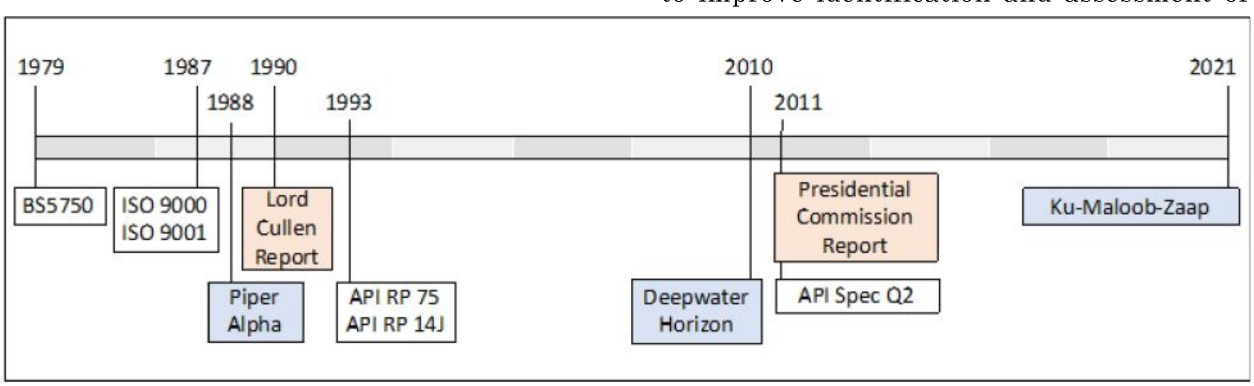

Figure 3. Timeline of Events and Safety Standards

inherent risks after their second audit in 2014 (OECD, 2017). Looking at the recent natural gas leak and fires in the Gulf of Mexico, evidence of implementation of these standards as risk control measures onsitemay be identified.

The design of the facilities incorporating risk control measures from 14 J, along with the swift action by the personnel to shut off supply from the pipeline inline with 75 SEMS, may have mitigated the severities of these events, despite the catastrophic loss of life in the second fire. Without the application of these standards incorporated into risk management and decision-making on the KUMAZA platform, the outcome may have been even more tragic. What remains to be seen is if the outcome of this tragedy will result in the adoption of API Spec Q2 to address any potential root causes or if further enhanced standards will be developed based on the outcome of the investigation.

Discussion: System 1 versus System 2 Thinking

The cycle of inadequate risk control and decision-making onsite, a shift to adopting existingbest practices but with poor implementation, a subsequent catastrophic event, and then the development of enhanced standards can be connected to the behavioral patterns of System 1 and System 2 thinking as applied in risk management and decision-making. System 1 thinking occurs automatically andinvoluntarily, while System 2 thinking requires mental activity and conscious effort (Kahneman, 2012).

These incidents described throughout the paper can be contributed to System 1 thinking engrained in the mindset and decision-making process even after it is understood that a safer and better way of going about things should be considered. Evidence of this includes how existing best practices were put in place before these incidents occurred but those best practices were not being fully implemented by the industry until after these catastrophic events. These events have made decision-makers reevaluate their decision-making processes and accept that those processes are not working appropriately. System 2 thinking occurs when events make people consciously reflect on their actions and put effort into changing how things have been done in the past, (McLeod, 2016). Over time this way of thinking becomes the industry standard and shifts back into System 1 thinking.

In the industry as a whole, there appears to be people in various roles that fall into System 1 and System 2 thinking. System 2 thinkers are constantly looking and reevaluating safety procedures and protocols. Such thinkers are commonly in the office and away from the day-to-day operations. Whereas the people who are on the wellsite, and unfortunately the people who are directly performing hazardous activities, tend to address risk management using System 1 thinking. They have pressures from above to perform faster and more efficiently, which compete directly with the drivers of System 2 thinking. Although the mindset begins to shift in the company itself it takes time to change the System 1 thinking and specially to adopt control measures derived from System 2 primary risk assessments.

System 1 can be both a negative and positive way of thinking when it comes to avoiding undesired outcomes for risky activities. System 1 can both drive a fresh perspective on risk analysis or could drive a complacent reaction to a hazard situation. One of the most dangerous phrases in the oilfield is "we've always done it that way." In this way, we can revisit our model of the cycle of the uptake of industry standards addressing risk management in the oil and gas industry. From this view, we can surmise that the initial reactions to a compelling event will be driven by System 1 thinking, up to and including the incorporation of existing standards to address immediate root causes. However, it is System 2 thinking that drives the creation of enhanced standards to address the full contribution of factors to compelling events. Unfortunately, it is this same System 2 thinking that does not demand the full adoption of best practices through improved standards implementation onsite until the subsequent compelling event.

Conclusion

With respect to risk management as applied to process safety in oil and gas operations, there exists a lag between the creation of industry best practices through the publication of standards, and the adoption of these practices to improve process safety and enhance operational integrity onsite. These standards can be considered as rules written in blood; created to address post-fact root cause analysis after compelling catastrophic incidents, including those tragic events that result in loss of life. Therefore, the reduction in the creation-to-adoption lag time relative to implementing regulation protocols is essential for the industry to continue to improve process safety, enhance operational integrity, and mitigate future undesired catastrophic outcomes for oil and gas operations.

The main question we sought to address through this analysis was how and when the oil and gas industry adopts best practices and enhanced standards, concerning process safety and operational integrity, after catastrophic events. Through the analysis of the case studies, we have proposed an adoption cycle for how the industry reacts to catastrophic events, with respect to the adoption of best practices, and creation of enhanced standards, to address the root causes of these events. Additionally, we attempted to address the question of how to have catastrophic events shaped risk management and decision-making in the oil and gas industry. In the analysis of the case studies themselves, we have sought to answer this question in detail. To summarize, System 1 thinking dominated initial reactions to each catastrophic event, through the integration of existing standards to address primary root causes. Subsequently, System 2 thinking drives the formulation of enhanced standards which more thoroughly deal with additional factors which contributed to compelling events.

During the course of the analysis, we also attempted to address the factors contributing to the adoption of best practices, through the application of SME standards, into risk management and decision-making onsite, and additionally how those best practices and standards impact process safety and operational integrity in the oil and gas industry. In deriving the conclusions for the primary questions addressed above, and the limited scope of the exercise, we have reached the opinion that additional opportunities have been opened for further research into these particular topics.

Further Research

Taking into consideration these benchmark case studies, the discussion of the timeline, and the organizational behavioral aspects concerning risk management and adoption of these standards, further research should be conducted to evaluate the nuances related to the timeline for adoption of industry best practices once a standard is published by API, ISO, or another SME. These nuances could include different organizational profiles for companies adopting a standard, such as:

- National oil companies vs international oil companies
- Major or super-major integrated oil and gas companies vs independent oil and gas companies
- Producers or service providers within the oil and gas industry
- Upstream, midstream, or downstream orientated oil and gas companies
- Regulatory framework within the country, basin, or area of operation for any of the above.

The outcome from the analysis could be utilized for further research related to best practices for standard adoption, once new standards are published. This could be useful information for all oil and gas industry stakeholders including public and private firms, governmental regulators, and SME organizations involved in the creation of standards. There exists a shared impetus for all stakeholders to reduce the creation-to-adoption timeline, for best industry practices, to as low as reasonably practical. This reduction is required to drive further continuous improvement in process safety and enhanced operational integrity for oil and gas operations. This is to ensure those who have contributed to these rules written in blood have done so to effectively prevent and mitigate future catastrophic outcomes that could result in loss of life.

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