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Risk, Oil Spills, and Governance: Can Organizational Theory Help Us Understand the 2010 Deepwater Horizon Oil Spill?

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Risk, Oil Spills, and Governance: Can Organizational Theory Help Us Understand the 2010 Deepwater Horizon Oil Spill?

A Thesis

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by

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Abstract

The 2010 BP Deepwater Horizon oil spill in the Gulf of Mexico awakened communities to the increased risk of large-scale damage along their coastlines presented by new technology in deep water drilling. Normal accident theory and high reliability theory offer a framework through which to view the 2010 spill that features predictive criteria linked to a qualitative assessment of risk presented by technology and organizations. The 2010 spill took place in a sociotechnical system that can be described as complex and tightly coupled, and therefore prone to normal accidents. However, the entities in charge of managing this technology lacked the organizational capacity to safely operate within this sociotechnical system.

Normal accident, high reliability, 2010, BP oil spill, Gulf of Mexico, technological disaster, Deepwater Horizon oil spill, environmental impact

Chapter 1: Introduction

The 2010 BP Deepwater Horizon blowout and oil spill in the Gulf of Mexico traumatized the Gulf coast and awakened society to the looming threat of new technologies in oil drilling that present risks many orders of magnitude larger than were present in the past. This thesis aims to answer a question that nags at the societal dependence on fossil fuels, which is: Are oil spills inevitable? Will the Gulf of Mexico, and later the Arctic tundra become the common victims of poorly understood environmentally exploitive practices? Are these accidents avoidable considering their highly technical and delicately balanced nature combined with the organizational failure inherent in human endeavors? This thesis will search for answers derived from accident theory and organizational literature to answer these questions, and will aim to draw conclusions and set forth policy recommendations based on the risk presented by dangerous new technologies.

Purpose of the Thesis

The goal of this thesis is to present a view of the 2010 BP Deepwater Horizon accident grounded in organizational theory that may offer insight to decision-makers and stakeholders in the Gulf region as well as other areas affected by or at risk of contamination from newly developed extractive technologies. The topic of the 2010 spill is significant because it exhibits the uncontrollable power of a technological accident as well as the conflict between reliance on unsustainable energy resources with the necessity to preserve ecological resources and environmental quality.

The analysis conducted in this thesis will address how the 2010 BP Deepwater Horizon blowout and oil spill can be characterized within disaster theory by attempting to answer the following questions: 1) Was the 2010 BP Deepwater Horizon Spill preventable within its existing sociotechnical system? Sub-question a) Do normal accident theory and high reliability theory apply to this event? Sub-question b) If these theories are applicable to this event, what indicators and criteria are appropriate for analysis? Sub-question c) How is the spill characterized in terms of these concepts and indicators?

The findings of this analysis will indicate whether the 2010 spill was inevitable based on indicators drawn from normal accident theory and high reliability theory. These findings weigh heavily in questions of whether or not to continue this risky technological endeavor, a topic partially broached by the advent of the 2010 spill and subsequent temporary moratorium on deep water drilling in the Gulf of Mexico. These questions also point to necessary changes to be incorporated into this sociotechnical system post-BP spill, and lend criteria by which to judge whether or not adequate steps have been taken to address these indicators of imminent disaster within the system. Finally, this thesis attempts to examine the tension between inherently accident-prone technology and organizational attempts to cope with this inherent risk in order to use this technology.

Narrative of the 2010 Deepwater Horizon Blowout

The 2010 Deepwater Horizon blowout event can be seen, as many accidents are in retrospect, as the result of errors and oversimplifications, an accretion of misread signals and an accumulation of faulty estimates in an unforgiving environment. The following narrative is largely drawn from the 2011 “Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout” published by the Bureau of Ocean Energy Management, Regulation and Enforcement, which details each step of the disaster and identifies technical causes of the blowout, and is supplemented by technical descriptions of events from other reports.

BP first established the Macondo well as an exploratory well in the Gulf of Mexico, a process which provided limited information about its hydrocarbon reserve, yet promised adequate reason to cement and “temporarily abandon” the well in order to facilitate future extraction processes (U.S. Department of the Interior / BOEMRE, 2011: 13-21; Deepwater Horizon Study Group, 2011). Temporary abandonment includes the cementing of the well and the installation of plugs to control hydrocarbon flow and facilitate extraction (U.S. Department of the Interior / BOEMRE, 2011: 14-15). It is important to note that the Deepwater Horizon rig was a dynamically positioned mobile offshore drilling unit (DP MODU). DP MODUs are “not moored to the seafloor but instead hold their position over the well through a combination of satellite technology and directional thruster activity (Ibid: 14).” This DP MODU apparatus was attached to the well bore (the hole in the hydrocarbon formation) through a drill “string” armed with a blow out preventer (BOP) stack which was located close to the well bore (Ibid 14-15).

The correct installation of a well depends on maintaining a balance between the pressure exerted by the formation on drilling and piping equipment and the capacity of the formation to withstand pressure (Ibid 27-28). Drilling mud is utilized to supply this balance, and is calibrated specifically to apply pressure to the formation that keeps the liquids within the formation in a controlled state. “In short, the mud must be heavy enough to control the pore pressure and ensure that the formation fluids (including hydrocarbons) do not enter the wellbore, while not so heavy that it fractures the formation (Ibid 27-28).” This narrow window between the pressures needed to maintain the integrity of the formation while controlling the substances within it is referred to in the drilling industry as the “drilling margin (Ibid, 27-28).”

The Macondo well was notorious for its peculiarity and difficult conditions before the accident occurred. The well presented problems in 2009, upon the first attempts to drill into it, when operators experienced well “kicks” in October 2009 and March 2010 (Ibid, 75-77). A kick is a serious well event referring to the “unwanted influx of formation fluids, such as hydrocarbons, into the wellbore (Ibid, 98).” It is crucial that operators identify these events in a timely fashion, as they can lead to a blow out situation, as eventually seen on April 20, 2010 (U.S. Department of the Interior / BOEMRE, 2011:21, 98; Skogdalen and Vinnem, 2012). With close monitoring and active response, however, operators have been known to control well kicks and prevent escalation of the situation (U.S. Department of the Interior / BOEMRE, 2011: 21, 98-99; Skogdalen and Vinnem, 2012). A second problem commonly experienced with the Macondo well was that of “lost returns” of drilling mud and fluid into the formation, which indicates a delicate formation that may have fractured in areas, allowing it to absorb fluid exerting great pressure on the formation at the time (U.S. Department of the Interior / BOEMRE, 2011: 19-20; Deepwater Horizon Study Group, 2011).

The goal of cementing the Macondo well was to achieve “zonal isolation” within the formation (U.S. Department of the Interior / BOEMRE, 2011:40). The standard procedure to cement and abandon a well includes cementing operations, pressure testing to make sure that the constructed well can withstand the environmental pressures, the setting of a casing, and placement of a cement plug into the well to secure it against pressure forces (Ibid, 2, 14-16, 20-21, 87). At the completion of these temporary abandonment procedures, the attending rig generally leaves the site to allow another rig to extract hydrocarbons from the well at a later date (Ibid, 14).

Many dormant issues belied the temporary abandonment procedures of the Macondo well, including a lack of information about the hydrocarbon formation, faulty well design, and a failure to cope with the significant lost material into the well formation as a result of the tight drilling margin (Ibid, 13-14, 20, 38, 41-47, 53-54). These dormant issues created a risky environment in which small errors in operations within the well could be magnified into large system accidents when combined with malfunctioning equipment and inadequate staff capacity.

On April 20, 2010 the crew of the Deepwater Horizon conducted positive and negative pressure tests to verify that the cement job in the well was adequately sealed and could withstand the pressure of the formation (Ibid, 21-22, 85). The positive pressure test was successful, however the two subsequent negative tests performed by the crew were largely inconclusive, but were interpreted incorrectly by the crew as being successful (Ibid 21-22, 88-97). Finally, on the evening of April 20, the crew conducted displacement procedures, in which they pumped out the drilling mud that had been used to maintain a pressure balance in the well, and replaced this mud with seawater in order to place the final seal on the well. During these displacement procedures, the hydrocarbon formation exerted immense pressure on the cement well structure with little balancing force exerted from inside the well (typically referred to as an underbalanced condition) (Ibid, 86-88, 94-103).

The well eventually experienced a well "kick" during these displacement procedures, which indicates the flow of hydrocarbons into the well and demands quick well control action, however the crew did not recognize this kick and failed to respond adequately, allowing hydrocarbons to flow up the well and onto the Deepwater Horizon deck (Ibid, 99-103). The crew then responded by diverting this flow to a mud gas separator that failed and spewed combustible gas within proximity to engines on the rig, which exploded and ignited the gas (Ibid, 103-106). The crew then attempted to initiate emergency procedures to activate the blow out preventer mechanism and disengage the Deepwater Horizon from the well, but these attempts failed due to multiple mechanical errors, leaving the well spewing oil and eventually sinking the Deepwater Horizon (Ibid 107-108, 129-144). Many of the crewmembers escaped the accident, however 11 members died and an estimated five million barrels of oil were released into the Gulf of Mexico. The Macondo well was capped and later sealed on September 19, 2010 (Ibid, 1, 24).

The 2010 spill took a large toll on the health of the various ecosystems and local economies of the Gulf of Mexico and the Gulf coast. It threatened the sensitive populations of migratory shorebirds, fish, and mammals with widespread and intergenerational consequences for these species (Henkel et. al., 2012; National Wildlife Federation, 2013). The deluge of oil suffocated the marshlands of the Mississippi River delta system (Lin and Mendelssohn, 2012), which serve a crucial function within the ecosystem and protect human settlements against the brutal hurricanes that attack the coast regularly. The oil and dispersants that cleanup workers and seafood customers contacted in the time following the spill are suspected to have caused a wide range of physical ailments (Goldstein et. al., 2011), and some authors have suggested that the toxicity of these elements in seafood products was not adequately represented in federal studies (Rotkin-Ellman et. al., 2012). The use of dispersants was criticized further because of the largely untested method of applying them within the context of the 2010 spill (Iaquinto, 2012), as well as their possible ramifications in the marine ecosystem (Zuijdgeest and Huettel, 2012; Berninger et. al., 2011). Finally, the spill had far reaching mental health and financial ramifications borne by the communities of the Gulf South, many of which are closely tied to the natural resources of the area for their livelihoods (Lee and Blanchard, 2012; Johnston Jr. et. al., 2012).

Analysts of the 2010 spill not only recognize the environmental impacts of the spill on the sensitive environment and fragile biodiversity of the Gulf of Mexico, but also note the deep economic impacts of this accident. Many predict long-term negative impacts to the commercial and recreational fishing and marine industries in the Gulf of Mexico and surrounding areas (Sumaila et. al., 2012), in addition to the immediate negative impact experienced by the fishing and tourism industries, and small businesses (Davis, 2011). The environmental, social, and economic repercussions of the 2010 spill cannot be understated, as they have irreversibly changed the Gulf coast.

The devastation resulting from the 2010 spill has left many residents searching for answers and solutions to prevent spills in the future. While the deep water drilling industry has grown, the increased risk to the environment and coastal livelihoods has grown with it, resulting in a conflict between profitable extraction and safety that is currently playing out in post-spill battles about legislation. This thesis aims to confront the question of whether or not the spill was preventable, and to shed light on how the sociotechnical system that controlled the operation of the Deepwater Horizon failed to prevent this catastrophe.

Chapter 2: Literature Review

A review of the literature on accidents within sociotechnical systems includes an assortment of theories that consider the temporal, probabilistic, structural, and organizational aspects of industries and processes that present technological risk to society. Many authors attempt to align characteristics of a system or organization with accident potential, while some theorists consider the human/technology interface in society and base their claims on communication as opposed to control. Most theorists in the field aim to improve the operations or policy surrounding industries that present a threat to humans, while others seek to illuminate the power structures that influence decisions concerning potentially catastrophic technologies.

Early Sociotechnical Disaster Theory

A thorough study of the literature on the organizational roots of technological disasters begins with Barry Turner's 1978 publication, *Man-Made Disasters*. In his survey of technological disasters, Turner analyzed the preconditions of disasters from a sociotechnical standpoint, including aspects such as imperfect knowledge distribution, centralization of decision-making, complex failures of compatibility, and gaps in responsibility (Turner 1978:3-6, 23-24, 58, 66).

Turner's research, like others in the sociotechnical disaster literature, links human control over processes that use or distribute energy with disaster risk and highlights the importance of communication in dangerous sociotechnical systems (Turner 1978:3,38, 121-124). One of Turner's most valuable contributions to sociotechnical disaster theory is his introduction of the "intubation period," a concept that describes the accumulation of minor errors and weaknesses that accumulate preceding, and eventually causing, a technological disaster (Turner 1978:86-90).

Turner's model is the basis of a later created time-based concept known as Disaster Incubation Theory (DIT), introduced by Turner and Pidgeon in 1997. DIT asserts that organizations can slip into complacency and suffer increased entropy and chaos as they accumulate dangerous precedents and practices that eventually combine to create an accident (Turner and Pidgeon, 1997 as cited in Shrivastava et. al., 2009). Shrivastava, Sonpar, and Pazzaglia, in 2009, refer to this trend toward increased accident risk through the accumulation of errors as "the gradual erosion of reliability," and thus link this train of thought with theoretical influences that strive to prevent accidents before they happen (Shrivastava et. al., 2009).

In contrast to Turner and Pidgeon's work on the accumulation of error in a temporal perspective (1997), some accident theorists have based their studies on James Reason's Swiss cheese model (SCM) of accident prevention, which considers the cumulative nature of errors and the relative probability of these errors occurring in tandem to facilitate a disaster (Reason, 1998 as cited in Shrivastava et. al., 2009). This theory can be visualized as layers of safety barriers (like pieces of stacked Swiss cheese) that combine to form a solid barrier with the exception of the situation in which the holes in the Swiss cheese align, thereby allowing an incident to occur (Reason, 1998 as cited in Shrivastava et. al., 2009).

Introduction to Normal Accident Theory

Charles Perrow's Normal Accident theory not only focused on the human/technology interface, as previous theorists had, it identified aspects of technical and social systems that make disaster not only possible, but unavoidable, or "normal" (Shrivastava et. al., 2009; Perrow, 1999: 5, 63, 333-334; Sagan, 1993: 28-29). In his normal accident theory, Perrow considers the structural and organizational contributing causes of technological disasters, and identifies two attributes -- complexity and coupling -- that serve as measures of a system's potential to create a disaster (Perrow 1999: 72-97). As dictated by the theory, the accidents that result from the confluence of these two attributes are considered "normal" or "system" accidents because they are *inevitable* given the level of complexity and tight coupling inherent in the subject *system* (Perrow, 1999: 5). Normal accident theory, as first described by Perrow, is based on the 'garbage can' model developed by Cohen, March, and Olsen (1988) and March and Olsen (1979). This model asserts that an organization may be characterized by many conflicting goals and uncertainty, and may therefore not always act as a rational actor, and may exercise bounded rationality[1] in decision-making (Perrow, 1994; Perrow, 1999: 323-324; Sagan, 1993, 29-31).

In his quest to identify why some industries or processes rife with safety procedures and defenses against failure still manage to experience major accidents, Perrow notes that the qualities of complexity and tight coupling within a system demand different specific authority structures in order for a given organization to cope with these technical challenges (Perrow, 1999: 330-335). A high level of interconnectedness between system components, reliance on indirect information sources, an unpredictable environment, or incomprehensibility of a system

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[1] The term "bounded rationality" refers to "limits on [humans'] thinking capacities and our inability to often achieve or even seek absolute rationality (Perrow, 1999: 323)." Rationality, in this instance, refers to perfect reasoning and consideration of all alternatives (Selten, 1999).

to its operators indicates complexity within a system (Perrow, 1999: 85-86). This quality may require specialized operator jobs and a decentralized command structure in emergent situations and accident prevention. This allows operators closest to the failing units or subsystems to exercise their knowledge to prevent escalation to a large-scale accident (Perrow, 1999: 332).

Tight coupling is often indicated by a tendency within the technical system for small failures to be magnified and instigate major failures elsewhere in the system with little time for intervention. Tight coupling, therefore, requires a centralized authority structure to effectively anticipate the effects of specific actions on the system as a whole. A central authority figure familiar with all of the parts of a system may be better equipped to handle tightly coupled interactions (Perrow, 1999: 333-335). An example of a centralized structure is a military hierarchy or the influence of strict accident training and procedures implemented in an industrial setting (Perrow, 1999: 333-335).

Normal accident theory asserts that a high level of complexity and tight coupling within a sociotechnical system predicts an accident within that system because the organizations that control these processes are unable to provide a simultaneously centralized and decentralized authority structure (Perrow 1999: 5, 334-335). This dilemma is an extension of contingency theories first developed by Burns and Stalker (1961) and Woodward (1965).[2] It leads Perrow to conclude that systems with these qualities are naturally prone to disaster regardless of their technical safety buffers or procedures (Perrow 1999: 4-5, 334).

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[2] Perrow draws from contingency theorists' assertion that "centralization is appropriate for organizations with routine tasks, and decentralization for those with nonroutine tasks (Perrow, 1999: 334)."

Complexity

The first attribute that Perrow identifies as a contributor to normal accidents within sociotechnical systems is that of complexity. Complexity describes such factors as the level of interdependency or interconnectedness among physical, chemical, or biological components of the system, the relative obscurity of the results of operators' commands, or the sheer incomprehensibility of the subject technical system to an operator who may be trained to focus only on a single component (Perrow 1999: 78, 88).

To illustrate the concept of complexity within a sociotechnical system, Perrow utilizes the concept of an assembly line as an example of a linear, and thus not complex, system (Perrow 1999: 72). Some indicators of complexity include multifunctional components within a system, proximity (enabling unforeseen interactions between separate components), reliance on indirect information sources, multiple "control parameters," specialization of personnel, and an uncertain environment[3] (Perrow 1999: 72-75, 84-86; Shrivastava et. al., 2009).

One example of a complex interaction based on proximity of two elements would be in Perrow's example of an oil tanker accident in which the oil storage location was near the engine room. Designers had not planned for these two areas to affect one another, however when an object pierced the hull of the ship, damaging the structural integrity of the oil storage and the engine room, the oil seeped into the engine room and ignited (Perrow 1999: 73-74). In this chain of events, two areas that were not planned to interact with each other did interact, causing an

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[3] A complete list of the indicators and a working definition of complexity is included in Appendix A, page 86.

unforeseen event – the fire. This is an example of complexity, illustrating that complexity within a system is directly linked with uncertainty and unpredicted interactions.

Coupling

The second attribute that Perrow identifies is “tight coupling,” which generally refers to the degree to which the action of one physical, chemical, or biological component within the system affects the action of another component (Perrow 1999: 89-93). Tight coupling, as defined by Perrow, refers to a process similar to a chemical reaction in that it must be buffered by safety designs such as redundancies, safety alarms, etc., due to a lack of human capacity to interfere in tightly-coupled processes at certain points (Perrow 1999: 90-94). However this concept can also describe processes that do not lend themselves to improvisation, such as processes that can only be completed in a specific order or where the substitution of parts or personnel is not possible (Shrivastava et. al., 2009; Perrow 1999: 90-94).

This definition applies to strict, highly monitored or regulated processes with little slack for improvisation within the context of an accident. Therefore, tightly coupled systems are somewhat less able to absorb shocks or changes within their normal operating environment and rather only perform correctly within specific limits of conditions and are often indicated by the presence of automatic safety buffers and redundancies[4] (Perrow 1999: 93-95).

A simple example of tight coupling can be seen in a chemical reaction, in which the addition of one chemical triggers a fast process change (for example the addition of baking soda

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[4] A list of the indicators and a working definition of coupling is included in Appendix A, page 86.

to vinegar triggers a bubbling effect). In contrast, the addition of baking soda to a mixture of flour, sugar, and eggs will not trigger a quick shift of the mixture into a batch of cookies, and instead this process requires the baker to execute many steps in a sequence. Coupling is therefore a time-based concept meaning that the speed of a reaction is directly indicative of coupling. Coupling is also a concept linked with direct causality, meaning that if one action invariably triggers a specific action, these two events are tightly coupled.

Other Factors Affecting Risk

In his survey of normal accidents, Perrow notes several factors (beyond complexity and coupling) within various industries that contribute to disaster risk, including production pressures, automated technology, conflicting agency goals, various legal incentives and liability, regulatory relationships, and the possible effects of a disaster, (Perrow 1999: 108-118, 131-132, 158-159, 166, 172-173, 176). Perrow also comments on a trend within dangerous sociotechnical systems whereby increased safety precautions or technology allow managers to push the limits of safeguards and operate within thin safety margins, ensuring increased efficiency rather than safer operation (Perrow 1999: 146, 180).

Perrow, in his review of Sagan's 1993 publication, highlights a number of organizational characteristics not previously specifically discussed within normal accident theory that affect the level of risk within a system including (Perrow, 1994):

- experience/duration spent to achieve an operating scale
- experience with "critical phases"

- the availability and open sharing of information on errors
- close proximity of elites to the system operations
- organizational control over members
- “organizational density of the system’s environment”

It should be noted, however, that Perrow does not make an effort to include these factors into his argument for the inevitability of disasters, and simply mentions them in passing.

In 1993, Scott Sagan applied normal accident theory to nuclear weapons accidents within the United States. In this analysis, Sagan adheres closely to the original definitions of complexity and coupling put forward by Perrow in 1984. Sagan, however, delves deeper into the influence of production pressures and regulatory relationships, and places an emphasis on power and relationships that dictate the management of technology with a high catastrophic potential (Sagan 1993: 37-39, 41-43, 207-210, 252-259).

Cost and Production Pressures within Normal Accident Theory

Perrow (1999) and Sagan (1993) both recognize that cost and production pressures have a direct and substantial influence on safety capacity within organizations. In his examination of cost and production pressures on sociotechnical systems with the capacity to create disasters, Perrow recognizes that many firms may externalize the risk or effects of their processes, thus resulting in a market failure. However Perrow insists that the capitalist system which allows this market externality is not at fault in this instance, as proven by the fact that sociotechnical production systems in non-capitalist systems are under the same production pressures as those within capitalist systems because they must compete globally[5] (Perrow 1999: 339-342). This line of thought would lead one to believe that cost and production pressures may play a part in creating risk within sociotechnical systems, but that these issues are not the main culprit in normal accidents.

In his analysis of explosions at chemical processing plants, Perrow concludes that cost and production pressures are a constant within industrial endeavors and that human organizations will predictably exercise some degree of human error and inability to detect important anomalies within their processes (Perrow, 1999: 111-112). By this description, Perrow appears to ignore the spectrum of influence that cost and production pressures or incompetence can have within different firms. Although he recognizes that these issues affect risk, Perrow does not provide measurable indicators of the degree of influence that cost and production pressures have on a system's proclivity to a normal accident.

In my opinion, Perrow's view of constant cost pressures and human ineptitude is an oversimplification within normal accident theory, as it seems that higher relative levels of cost and production pressures play a part in dramatically increasing complexity and coupling beyond the level inherent within the technical system. These trends also appear to have the effect of lowering levels of safety and preparedness for accidents. Examples of this phenomenon may include utilizing faster or more efficient processes that increase common-mode components (an indicator of complexity) and shorten time for human intervention into processes (tightening coupling). One example of the connection between cost pressures and coupling can be observed

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[5] It should be noted that this description of the relationship between capitalist systems and production pressures was written in 1984 and republished in 1999, and therefore may not adequately describe the current global marketplace brought on by increased globalization in the 21st century.

in Perrow’s description of the reduction of staff numbers in flight crews (prompted by financial savings), which “will lead to much tighter coupling – that is, less resources for recovery from incidents (Perrow, 1999: 161).”

Sagan focuses on cost and production pressures through the lens of evaluating the applicability of normal accident theory to nuclear weapons accidents in the U.S. In his analysis, Sagan notes that the organizational results of production pressures, for example hasty decision-making and procedures conducted in a rushed and imperfect fashion, often accompany a normal accident, thereby linking these concepts, rather than commenting on them as separate phenomena within a system (Sagan, 1993: 36-38). Although Perrow and Sagan provide observations on the relationship between cost and production pressures, this factor is not adequately represented in the main concepts and indicators of normal accident theory.

Normal accident theorists discuss cost and production pressures as contributing to accident risk, but do not list measurable indicators of the degree to which these qualities contribute to systemic failure. Based on this treatment of the variable of cost and production pressures within normal accident theory, I hypothesize that normal accident theory is not capable of adequately describing all system accidents and fails to address the critical influence of cost and production pressures on accident risk.

Interests and Power in Normal Accident Theory

Perrow and Sagan have elaborated on group interests and power (Sagan, 1993 as cited in Perrow, 1994), structural incentives for neglecting safety (Perrow, 1994), and organizational learning impeded by ineffective communication (Sagan, 1993: 252-259) within the context of normal accident theory.

One major way in which normal accident theory addresses power issues in accidents is the transfer of blame in accidents from ‘operator error’ to system dysfunctions and interactions (Perrow 1999: 63). This implies that many accidents may be the result of a system that includes budget cuts to critical safety processes, poorly designed equipment, and a push toward increased production, yet the accident that results from this system may be blamed on operator error.

In his research into “accident inducing systems,” such as the marine transportation industry, Perrow (1999) cites failures in management that are directly related to power structures encouraging unsafe operation. Perrow contends that limited financial loss in the event of an accident, inelastic demand, low-status or anonymous victims, delayed accident effect, and the absence of elites as victims in the risky system are factors that promote unsafe operation from a management perspective (Perrow 1999: 67-70, 171-173). Perrow further argues that managers of dangerous technologies are prone to perverse incentives built into the management structures of firms that punish expenses and delays associated with safety precautions, and that allow managers to make decisions that ignore an accident’s latency period (Perrow, 1994).

Sagan, in his 1994 response to Perrow’s article, agrees and adds that institutional mindsets may prevent improvements in safety even after an accident due to reflexive adoption of redundancy, and failure to actually learn lessons from mishaps due to agency secrecy and competition as well as a false confidence in the ability to avoid disasters (Sagan, 1994).

Criticisms of Normal Accident Theory

Normal accident theory is imperfect, and has been thoroughly critiqued within the organizational accident literature. The most significant critique of normal accident theory leveled by Hopkins (1999) is that the theory, as originally developed by Perrow, applies to a very narrow category of accidents and that it is difficult to adequately determine which accidents are described by normal accident theory. An example of this issue can be seen in Perrow's 1994 article in which the author does not classify the gas leak in Bhopal, India in 1984, the Challenger space shuttle disaster, the Chernobyl nuclear reactor accident, or the spill of the Exxon Valdez oil tanker as normal accidents[6]. Many critics conversely argue that some of these major accidents have taken place in seemingly complex and tightly coupled systems (Hopkins, 1999; Shrivastava et. al., 2009).

Hopkins (1999) further criticizes Perrow, in his original construction of normal accident theory, for a lack of criteria by which to place specific industries or processes within his matrix of complexity and coupling. Perrow, in response to this common critique of his theory, agreed that a unit of measurement of the small errors within sociotechnical systems with the capacity to disrupt the system by bypassing safety measures is necessary (Perrow, 1994).

Shrivastava et. al. (2009) note an additional critique in that normal accident theory utilizes the concepts of complexity and coupling as if they are static characteristics of a system. Shrivastava et. al. (2009) contend that complexity is a relative concept subject to the cognitive

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[6] Although many of these events can be classified as "disasters" rather than "accidents" due to their devastating scale or nature, Perrow does not distinguish between disasters and accidents throughout his 1999 publication, and uses the term "accident" to describe large-scale system failures – thus designating more weight to this word that its standard connotation would imply.

capacity of operators within a system and that coupling is subject to the degree of conceptual slack allotted to operators within a system (Schulman 1993 as referenced in Shrivastava et. al., 2009). Based on these considerations, Shrivastava et. al. argue that Perrow overlooks a human component in complexity and coupling. Their critique focuses on the flawed, rigid view of a system provided by normal accident theory (centering on the paradox of centralized v. decentralized control). These authors insist that sociotechnical systems include variable human elements that allow for flexibility in coping with complexity and coupling (Shrivastava et. al., 2009).

Another critique of normal accident theory is that proponents of the theory have generally compiled and tested their theory through the analysis of archival data found in accident reports (Roberts, 1990; Bain, 1999). This method clearly has its faults, including a lack of pertinent details and explanations, as well as the possibility of firms intentionally withholding information. In response to this criticism, however, Perrow warns against accident researchers 'going native' in the search for empirical evidence, and thus neglecting to anticipate failures within their respective organizations (Perrow, 1994).

Normal accident theory has significant issues in its application to accidents and sociotechnical systems. As alluded to on pages 15-19, this theory attempts to describe inherent risk in sociotechnical systems using the variables of complexity and coupling, however this classification system ignores many major concepts such as cost and production pressures and power structures. Although both Perrow and Sagan acknowledge these factors as important, normal accident theory fails to provide measurable indicators for these concepts, and relegates these ideas to the status of side issues. High reliability theory, detailed below, may serve to supplement these deficiencies within normal accident theory, by providing an organizational perspective that places emphasis on organizational learning, the prioritization of safety, and the formation of a ‘culture’ of reliability within a firm or industry. These two theories, in combination, may also apply to a broader range of accidents, as they provide social and technical indicators of risk[7].

An application of normal accident and high reliability theories to an accident event is, by its nature reliant on accident reports. This method therefore does not account for the dynamic characteristic of risk over time (as alluded to in Shrivastava et. al., 2009), and only offers a snapshot of the sociotechnical system in which the subject accident took place.

Although normal accident theory and high reliability theory, as drafted by their seminal authors, do not include specific criteria to link accident causation with the indicators of main theoretical concepts such as complexity, safety prioritization, etc., this thesis attempts to establish criteria for these concepts based on an examination of their narrative application within the literature.

Answer to Normal Accident Theory: High Reliability Theory

High reliability theory refers to the study of organizations in charge of high-risk technology that experience very few accidents. This realm of accident theory developed in the late 1980s and early 1990s in direct response to Perrow’s normal accident theory (Sagan, 1993:

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[7] Many high reliability theorists, in fact, insist that their method applies to a broader range of accidents than does Perrow in his 1994 article – see Hopkins 1999, Shrivastava et. al., 2009, La Porte 1994, Roberts 1990b, Roberts and Bea, 2001.

14-16; Shrivastava et. al., 2009; La Porte and Consolini, 1991; La Porte, 1994). High reliability theorists generally responded to Perrow's theory by asking: If complexity and coupling lead to inevitable accidents, why have some firms in charge of seemingly complex and tightly coupled processes avoided system accidents? These theorists specifically considered the frequency of 'near misses' or avoided accidents and the extensive safety record of some organizations. From these they identified common management themes that successful firms employed to greatly reduce or eliminate accident potential (La Porte and Consolini, 1991; Roberts, 1990b).

Scholars at the University of California at Berkeley including Todd LaPorte, Paula Consolini, Gene Rochlin, Karlene Roberts, and Robert Bea, and at the University of Michigan at Ann Arbor including Karl Weick and Kathleen Sutcliffe, pioneered research into high reliability organizations. These scholars asserted that organizations can avoid system disasters by practicing organizational learning and "sophisticated methods of trial and error," while prioritizing safety above all other objectives and socializing operators to work within a decentralized authority structure while harboring a common operating culture (La Porte, 1994; La Porte and Consolini, 1991; Sagan, 1993: 16-24; Roberts and Bea, 2001; Weick, 1987).

More specifically, high reliability theorists look at the ways in which organizations in control of high hazard technologies seek out weak links in their processes and methodically adjust their processes to accommodate a changing environment (Roberts and Bea, 2001; Sagan, 1993:25). Roberts, in her account of a nuclear aircraft carrier's processes, emphasizes constant training as well as an authority structure that designates responsibility to the lowest ranking members of the organization and allows for negotiation with leadership, thereby introducing flexibility and decentralization into a traditionally hierarchical structure (Roberts, 1990b).

The tenets of high reliability theory are somewhat more diffuse than those presented by Perrow and Sagan in normal accident theory, due to their diverse authorship. From these numerous contributors, however, organizational learning, prioritization of safety, and organizational "culture" stand out as three common threads that high reliability theorists discuss as aiding in the vigilance and resilience of an organization.

Organizational Learning

Much of the literature on high reliability organizations focuses on these firms ability to learn over time and incrementally adjust their processes to reduce failure. In his description of high reliability theory, Sagan suggests that although trial and error serves as an opportunity for organizational learning to take place (as suggested by Wildavsky), high reliability firms must often rely on "simulations and imagination of trials and errors" to improve their processes because the social cost of their failure is so high (Sagan, 1993: 25-26; Wildavsky, 1988: 17 as referenced in Sagan, 1993). Roberts and Bea add to this concept by noting that some high reliability organizations practice almost constant training or accident imagination, and are able to identify parts of the system that require redundancies as a result of organizational learning (Roberts, 1990a, Roberts and Bea, 2001).

Prioritization of Safety

The prioritization of safety is a critical concept in high reliability theory. Many high reliability theorists argue that a reduction in accidents within a given sociotechnical system is only possible if both elites and managers recognize that the social cost of an accident is unacceptable, and therefore prioritize safety as the primary objective of the organization (La Porte and Consolini, 1991; Roberts, 1990a; Sagan, 1993: 17-19). This assertion that safety must be prioritized, however, speaks to two social concepts: first, that elites (regulators and those with power) must have a stake in the avoidance of accidents within these systems and second, that managers within the entirety of a firm must prioritize safety over profit or efficiency (Sagan, 1993: 17-19).

Organizational Culture

A third concept embraced by high reliability theorists is that of an organizational culture that serves to socialize operators thoroughly so that they use common operating procedures and decision-making reasoning (Roberts, 1990b). This culture, if implemented correctly, allows for decentralization within the authority structure of a firm – addressing emergency situations or peak load periods – while maintaining a consistent set of assumptions and goals within the group of operators serving a firm (Roberts, 1990b; Sagan, 1993: 21-25; Roberts and Bea, 2001). High reliability theorists list qualities such as open communication, clear designations of responsibility, and adequate training of employees as key factors in the cultivation of a safety-oriented organizational culture within a firm (Roberts and Bea, 2001; Sagan, 1993: 21-25; Roberts, 1990b).

High Reliability Theory vs. Normal Accident Theory

Some organizational theorists have attempted to contrast high reliability theory with normal accident theory, thus framing the two theories as competing perspectives (Perrow, 1994, Sagan, 1993). This inclination is likely based on the fact that normal accident theory and high reliability theory do not neatly rest on the same theoretical assumptions concerning rationality, organizational structure, or the importance of redundancy (La Porte 1994, Sagan, 1993:16-28).

One example of these theoretical differences is that high reliability theory, unlike that of normal accident theory, insists that redundancy (in terms of mechanical functions or people) can improve safety by "[making] a reliable system out of unreliable parts" (La Porte, 1994; Roberts, 1990b). Because this has been a point of the dispute between the theories and due to its lack of conceptual prominence in recent publications[8], this concept will not be considered as a main tenet of high reliability theory within this thesis, however it is significant that this concept appears in the high reliability theory literature.

More significantly, high reliability theory is often either tacitly or explicitly based on a rational model of organizations, and therefore claims that organizations can prioritize safety above all other objectives, an assertion that conflicts with Perrow's adoption of the garbage can model in normal accident theory (La Porte, 1994; Perrow, 1994; Robers, 1990b). Finally, some high reliability theorists claim that "nearly error-free" organizations are able to experience the benefits of a centralized and decentralized authority structure simultaneously through intense socialization and communication, a notion that goes against Perrow's assertion that these modes

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[8] Examples of this include Roberts and Bea, 2001 and Shrivastava et. al., 2009.

are mutually exclusive (Roberts, 1990b; Roberts and Bea, 2001; La Porte 1994; Shrivastava et. al., 2009).

Although high reliability theory clearly expresses differences with the premises of normal accident theory, many theorists hold that these two theories are not competing perspectives, and rather function as “blindfolded observers feeling different parts of an elephant (Rosa, 2005)” (Shrivastava et. al., 2009; La Porte, 1994). Additionally, both normal accident theory and high reliability theory have been described as incomplete or featuring an “under-developed systems perspective that warrants a synthesis of the two concepts in analysis of accidents (Shrivastava et. al. 2009).” The symbiosis between the two theories may be observed within the framework of a structural view of a sociotechnical system as exemplified by normal accident theory accompanied by a view of power and safety culture based more in management, as exemplified by high reliability theory (Rosa, 2005).

Because high reliability theory evolved as a response to the organizational challenges set forth by normal accident theory, namely complexity and coupling, high reliability theory is often framed as an attempt to answer these challenges (Roberts, 1990b; Shrivastava et. al., 2009). This relationship sets up a dialogue between the measures of normal accident theory concepts, which set forth the degree to which the sociotechnical system is burdened by complexity and coupling, and the measures of high reliability theory concepts, which measure the ability of an organization to cope with complexity and coupling.

Criticisms of High Reliability Theory

Due to its predominant focus on organizational and social factors, one clear criticism of high reliability theory, made by Perrow, is that it ignores technical or environmental factors within a sociotechnical system and only looks to management in disaster causation (Perrow, 1994). This is an apt critique that is clearly addressed by the combination of a technical system analysis based on normal accident theory accompanied by an application of the tenets of high reliability (Roberts, 1990b; Shrivastava et. al., 2009; La Porte and Consolini, 1991). An additional critique of this theory is that its link to causality cannot be entirely proven due to a lack of "systematic comparisons with non-HROs" (Shrivastava et. al., 2009). This critique appears to be a temporary issue, as further development of high reliability theory could seek to address this lack of evidence.

A third, and more damning critique of high reliability theory, which also applies to normal accident theory, is that of the accusation of non-falsifiability as noted by Rosa (2005) and reiterated by Shrivastava et. al. in 2009. Shrivastava et. al. comment on this flaw by asserting that normal accidents theory and high reliability theory can neither be proven nor disproven in practice based on the lack of measurable concept criteria presented in each theory (Shrivastava et. al., 2009). This criticism of both theories may be addressed through further development of indicators and criteria identifying main concepts within the theories, as well as the growth of empirical studies applying these concepts to industrial practices (Shrivastava et. al., 2009; Rosa, 2005).

Constructivist Approaches to Sociotechnical Systems

Normal accident theory and high reliability theory (as well as their predecessors such as disaster intubation theory) are all based on organizational theories that specialize in a rational approach to technical problems, thereby marking a separation between human and non-human actors in a sociotechnical system. Other theoretical perspectives related to disasters in sociotechnical systems provide an alternative interpretation of this relationship, including science, technology, and society (STS) studies, actor-network theory, and the social construction of technology. STS basically refers to a branch of scholarship that focuses on the relationship between societal values and scientific research. STS focuses on the social context of scientific discoveries and contributions, and questions the strictly empirical aura surrounding scientific claims. Instead, it presents the notion that scientific knowledge may be socially constructed or at the very least may be affected by the social context in which it takes place (Radder, 1992).

Actor-network theory (ANT), largely developed by Michel Callon, Bruno Latour, and John Law, focuses on the relationship between human and non-human actors within a system. Described as material-semiotics, ANT is innovative in its consideration of technology within a network as an "actant," placing emphasis on the network of ideas, tools, machines, and humans or operators (Radder, 1992). Actor-network theory presents an interesting contrast to theories emphasize the technical structure or organizational control of accidents, as actor-network theory focuses attention to the relationships and connections between actors, as opposed to the control of technology through science or society (Radder, 1992).

Radder, in his publication on constructivist theories regarding science, contrasts the normative suggestions in Perrow’s normal accidents theory with Latour’s actor-network theory noting that while constructivist theories on science and technology may not specifically offer direct policy guidance for the prevention of accidents, these theories do not lack a normative angle, because all approaches to science, including those labeled ‘disinterested’ have normative ideas underlying their practice (Radder, 1992). The author further notes that a broad normative strategy that can be gleaned from an actor-network theory approach to technological accidents is to implement projects with minimal catastrophic potential that are democratically supported by all of the citizens involved in the process (including those affected by potential accidents) (Radder, 1992). This perspective on adequate technologies seems to blend easily with Perrow’s undertone of criticism for an unequal balance of power and risk with regard to technological accidents (Perrow, 1999: 304-305, 309, 320-323, 341-342).

Differing Concepts of Reality

Various theoretical approaches to disaster causality hinge on conceptions of reality and the possible multiple perspectives of reality in a given situation. Gephart (1984) proposes an additional “political sensemaking model” which embraces the notion that there is no one objective version of reality.

Gephart has many disagreements with Turner’s theory including: 1) Gephart asserts (contrary to Turner’s rational model) that there is not one singular reality that operators in an emergency situation are having trouble grasping, but instead there are multiple constructions of reality based in language that are expressed by opposing sides; and 2) Gephart disagrees with

Turner’s assertion that the preconditions for disaster happen right before the accident and are not seen because of faulty paradigms of thought (Gephart, 1984). In this disagreement, Gephart asserts that the preconditions for a disaster can last for a long time, using the infamous “Love Canal” debacle as an example (Gephart, 1984).

It should be noted that many authors have grappled with the disconnect between operators’ conceptions of reality and objective reality (later outlined in accident reports) in the context of a technological system accident (Turner, 1978: 50-58, 128-129, 138-146, 154-156; Perrow, 1999: 274-278; Weick, 1988). Gephart adds to this realm of theory by offering the concept that no one version of reality is correct and that the reality of a situation changes with its observer.

Chapter 3: Research Methods

The research questions that I seek to address in this thesis are:

1. Was the 2010 BP Deepwater Horizon oil spill preventable?
    a. Do normal accident theory and high reliability theory apply to this event?
    b. If these theories are applicable to this event, what indicators and criteria are appropriate by which to determine if the event was preventable?
    c. How is the spill characterized in terms of these five main indicators?

Normal Accident Theory and High Reliability Theory in Application

In order to answer my primary research question, "Was the 2010 BP Deepwater Horizon oil spill preventable?" I will use normal accident theory and high reliability theory, in tandem, to identify the sociotechnical and organizational causes of the accident. By applying these theories together, I will attempt to find whether complexity and coupling indicated a predication toward a system accident (as set forth by normal accident theory), and whether the social system including the Deepwater Horizon rig crew, management, and regulators functioned as a high reliability organization with the capability to prevent such system accidents from occurring through effective system management.

This thesis will utilize the concepts of normal accident theory and high reliability theory developed by Perrow (1994, 1999), Sagan (1993, 1994), La Porte (1994 and 1991 with Consolini), Roberts (1990 and 2001 with Bea), Weick and Sutcliffe (2001) and Shrivastava et. al. (2009). I will apply criteria developed by the aforementioned authors to the causes, contributing causes, and possible contributing causes of the BP spill identified in the 2011 Bureau of Ocean

Energy Management, Regulation and Enforcement (BOEMRE) “Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout” and the 2011 National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling Chief Counsel’s Report entitled “Macondo: the Gulf Oil Disaster.”

Methodology

The boundaries of the sociotechnical system that this thesis will analyze include the Deepwater Horizon rig and the Macondo well (including all of the machinery, parts, and materials therein), the operators and managers atop the rig, the managers and corporate leadership of BP and its operating partners, and the regulatory regime of the Minerals Management Service in April 2010 as it applied to the Macondo well project. My unit of analysis will be the mechanical components (for example: the BOP stack, the drilling pipe, or the float collar) and, in the instance of social factors, the decisions, or specific lack of action (for example: the decision to use lost circulation material as a spacer, the failure to notify engine personnel of gas alarms) that occurred within the sociotechnical system. Larger-scale factors, such as the global economy, are generally outside of this boundary.

I have chosen to apply the normal accident theory concepts of complexity and coupling and the high reliability theory concepts of organizational learning, prioritization of safety, and organizational culture to the subject case study through the use of a series of indicators as listed in Figures 1 and 2 (pp. 37-38). I will analyze each causal factor according to its alignment with the indicators of normal accident theory, high reliability theory, or “other” (to indicate that the causal factor does not fall into a category deemed significant within one of the two theories and may be explained by a different theoretical approach). I will then construct a matrix to visually represent these findings. It should be noted that this analysis is qualitative and based on a single rater, and therefore may be influenced by analyst bias or a bias expressed within the accident reports (sources of data). Because of these conditions, some level of error will be built into this analysis.

Upon classifying all of the causal factors of the spill, I will calculate the cumulative number of factors that signify each theoretical concept, as well as their percentage of the total. Although some causal factors may be linked to multiple theoretical concepts, the resulting percentages will roughly indicate the weight of each concept in the causation of the spill. I have set criteria to demarcate relative degrees of each concept's influence in the causation of the spill, which are listed and explained in Figures 1 and 2 (pp. 37-38). I aim to determine if the subject sociotechnical system failed to prevent the Macondo well blowout due to complexity, tight coupling, a lack of organizational learning, lack of prioritization of safety, or an inadequate organizational culture[9]. This cumulative analysis of causal factors will assist in determining to what degree factors such as technical complexity or coupling, centralization of command structure, production pressures, knowledge gaps, and political/corporate power structures affected the accident.

I have decided to apply normal accident theory and high reliability theory simultaneously to this event because they are the dominant theoretical influences in the field of organizational

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[9] I describe tenets of high reliability organizations in a negative manner, because the goal of the thesis is to answer whether or not a lack of these qualities led to the accident.

analysis of sociotechnical disasters[10] as noted by several theorists who have recently urged a combination of the two methods (Shrivastava et. al., 2009; Rosa, 2005). Additionally, the combination of the two theories allows for a broader application to a range of disasters, as well as a more thorough examination of organizational causes of disaster, as each theory supplements the weak points of the other. An example of this supplementary usage can be seen in the fact that normal accident theory does not adequately set forth indicators to measure the effect that cost and production pressures have on risk levels within a system, however high reliability theory features indicators for the prioritization of safety that directly speak to this issue. Similarly, while high reliability theory does not adequately address the possible failure of mechanical components except through the concept of training and adaptation, normal accident theory provides indicators to assess the level of inherent technological risk through complexity and coupling.

This complimentary relationship is apparent in my analysis, as many technological failures can be attributed to complexity and coupling, while many managerial failures can be attributed to a lack of organizational learning, lack of prioritization of safety, or inadequate organizational culture. My application of normal accident theory concepts to technical aspects of the Deepwater Horizon system is in keeping with the method by which Perrow employed the theory to multiple case studies in his 1999 publication on a component and decision level (Perrow, 1999: 15-32, 123-179). Similarly, my application of the concepts of high reliability theory to motivations or strategies aimed at addressing complexity and tight coupling is consistent with Karlene Robert's analysis of high reliability as applied to nuclear aircraft carriers

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[10] The dominance of these theories within organizational accident literature is similarly exemplified by the number of citations per work as follows: Perrow, 1984/1999 – 2,043; Sagan, 1993 – 274; La Porte and Consolini, 1991 – 161; Weick and Sutcliffe, 2001 – 549; Roberts, 1990b – 144; Weick, 1987 – 226 (Thomson Reuters Web of Science Social Science Citation Index).

(Roberts, 1990b). Through the application of both theories, I aim to take a well-balanced approach to the causes of the disaster that considers both social and technical contributors to the spill.

Indicators and Criteria

A table of concepts, indicators, and criteria for normal accident theory and high reliability theory are provided on the following pages to illustrate the concepts presented above as applied throughout this thesis. The author has hypothesized criteria to determine the severity of these concepts in accident causation drawing on application of both theories to case studies and industries.

Figure 1: Author-Identified Concepts, Indicators, and Criteria of Normal Accident Theory

Normal Accident Theory		
Concepts	Indicators	Criteria
Complexity	• Proximity of parts or units that are not in a production sequence • Many common mode connections between components (parts, units, or subsystems) not in a production sequence • Unfamiliar or unintended feedback loops • Many control parameters with potential interactions • Indirect or inferential information sources • Limited understanding of some processes	Subject accident is a 'normal' or 'system' accident = 50% concept indicators linked to complexity and tight coupling, collectively. Significant factors = 25% or more concept indicators linked to one concept.
Tight Coupling	• Delays in processing not possible • Invariant sequences[11] • Only one method to achieve goal • Little slack possible in supplies, equipment, personnel • Buffers and redundancies are designed-in, deliberate • Substitutions of supplies, equipment, personnel limited and designed in	

Indicators drawn from Perrow, 1999: 85-96.

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[11] "Invariant sequences" as defined by Perrow, refers to the notion that some highly technical processes can only be carried out through a specific sequence of steps in order. Perrow uses the contrast between the assembly of an aircraft (which has a variable sequence) to the generation of energy from a nuclear reaction (which has an invariant sequence) to illustrate this quality (Perrow, 1999: 93-94).

Figure 2: Author Identified Concepts, Indicators, and Criteria of High Reliability Theory

High Reliability Theory		
Concepts	Indicators	Criteria
Lack of Organizational Learning	• Organization does not adjust its procedures and routines over time to evolve with challenges • Organization does not learn from errors or accident simulation • Organization does not conduct thorough accident investigations • Organizational hubris is apparent in a lack of accident imagination or foresight • System managers fail to identify parts of the system that should have redundancies	Not a leading factor in the spill = Less than 10% of decisions /action indicate a lack of organizational learning Significant factor = 10% or more
Lack of Prioritization of Safety	• Elites and system managers do not prioritize safety over short term profit or efficiency and production is valued at the expense of safety • Incentive systems do not reward safety and instead may reward profit or efficiency • Publicly stated safety goals do not coincide with operating culture	Not a leading factor in the spill = Less than 10% of decisions /actions indicate a lack of prioritization of safety Significant factor = 10% or more
Lack of adequate organizational culture	• Organization does not assign responsibility and accountability to low level employees, adheres to a hierarchical structure • Lower level operators do not have authority to make safety decisions • Decision-makers do not defer to experts • Organization does not facilitate open and free communication • A homogeneous set of assumptions and premises does not exist between workers and common operating procedures are not used or enforced • Authority structure does not accommodate centralization and decentralization simultaneously • Organization does not conduct exercises or simulations on an ongoing basis • Organization does not train employees to recognize and respond to anomalies	Not a leading factor in the spill = Less than 10% of decisions /actions indicate a lack of adequate organizational culture Significant factor = 10% or more

Indicators drawn from: Sagan, 1993:14-27, Roberts and Bea, 2001, Roberts, 1990a, Roberts, 1990b, Weick and Sutcliffe, 2001: 10-17.

Development of Criteria

A normal accident is an accident caused by the confluence of complexity and coupling within a sociotechnical system. Based on this premise, I have determined that the 2010 BP Deepwater Horizon oil spill can only adequately be described as a normal accident if the identified concept indicators for complexity and coupling collectively signify 50% or more of the total number of concept indicators. By this logic, a level of 25% or above of total concept indicators for complexity or coupling would indicate a significant level of this quality within the subject sociotechnical system. Alternatively, many of Perrow's analyses of accidents within industrial processes include high levels of either complexity or coupling within a system (47-57 % of listed causal factors). Without both of these attributes, however, these systems do not produce 'normal accidents' and instead demonstrate accidents that were either predictable (not complex) or allowed for recovery from failure (not tightly coupled)[12]. This possibility points to the notion that the important criterion in measuring these concepts is their collective ability to describe the cause of an accident.

Because high reliability theorists strive toward creating organizational capacity to nearly eliminate accidents, I have set the criteria by which to determine the degree to which an accident is caused by one of these concepts at relatively low levels. A main tenet of high reliability theory is strict adherence to these principles and constant vigilance, indicating that if an organization owes even a small percentage of its failure to these

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[12] The examples of these types of systems set forth in Perrow's 1999 publication are that of a dam failure (low complexity, tight coupling) and a dispute between students and a university over tenure policy (high complexity, loose coupling). These examples can be found in Perrow, 1999: 98-99, 232-241, and an analysis of the levels of complexity and coupling in these examples can be found in Appendix B, Figure 2, p. 121.

concepts, this is a significant lack of reliability within the organization (Roberts, 1990b; La Porte and Consolini, 1991).

Accident Reports in Application

In my analysis of causes of the 2010 blowout, I will rely heavily on the September 14, 2011 "Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout" by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) and the 2011 National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling Chief Counsel's Report, "Macondo: The Gulf Oil Disaster," known hereafter as the "BOEMRE report" and the "National Commission Report."

I have selected the BOEMRE report to analyze the technical failings that led to the 2010 spill, as this report follows a strong cause and event chain and thoroughly details both mechanical failures and failures in decision-making made by the crew and management of the Deepwater Horizon. This report is well organized and chronologically details the failures on the rig leading to the 2010 blowout. This report summarizes the technical findings of the Joint Investigation Team made up of appointed members of BOEMRE, the BOEMRE Investigative Review Unit, and the U.S. Coast Guard. The report draws from the findings of expert analyses of the blowout protector stack (conducted by Det Norske Veritas), the well condition data (conducted by Dr. John Smith -Petroleum Consulting LLC), buoyancy analysis (conducted by Keystone Engineering), and cement blend analysis (conducted by Oilfield Testing and Consulting). Finally, this report is useful because it designates specific causes, contributing causes, and possible contributing causes of the blowout based on these technical findings. The

2011 BOEMRE report is the most comprehensive and authoritative report on the disasters technical causes to date.

Although the BOEMRE report appears to be an accurate recount of the technical failings aboard the Deepwater Horizon, it should be noted that this report has been published by the very agency (MMS, now BOEMRE) that regulated deep water drilling permits and safety within the Gulf of Mexico at the time of the spill, and continues in this task, indicating a possible source of error in the collected data[13]. The 2011 report, however, is not the sole work of BOEMRE. The authorship of the report is credited to the Joint Investigation Team and the U.S. Coast Guard. It is not surprising, in light of the authorship of this report, that the report deals mainly with identifying failures by BP and its partners and contractors rather than pointing to regulatory or systematic failure.

I have selected the National Commission report to supplement the BOEMRE report because it places a larger emphasis on the organizational and regulatory failure that led to the 2010 spill. This report, released to the President, is geared toward a systematic approach to the spill including a thorough examination of the regulatory regime surrounding the event. Although this report does not designate specific actions or decisions as causes, contributing causes, or possible contributing causes, it does imply that some decisions weighed more heavily in the accident than others, and this has been taken into consideration in my analysis of these actions or decisions. The National Commission report is the most comprehensive and authoritative report available to date on the social causes of the 2010 oil spill.

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[13] The reorganization of MMS to BOEMRE included a separation of promotion/lease sales and safety enforcement, so these functions may be significantly more separate than they were at the time of the spill ("Reorganization of The Bureau of Ocean Energy Management, Regulation and Enforcement").

The National Commission was formed by executive order shortly following the spill, and was made up of members of the federal government from different agencies including the Environmental Protection Agency, the Department of Energy, as well as members of nongovernmental organizations such as the Natural Resources Defense Council (National Commission…, 2011e). Due to the varied background of the commission members, one can surmise that the report does not hail from a single agency with a unified purpose, and may include perspectives beyond that of BP and its direct regulatory counterparts (Goode, 2010; Boesch, 2010; "The Antidrilling Commission").

Both of the reports used in this analysis lend themselves to classification as reflexive, rather than innovative "lessons learned" documents, meaning that they offer findings and recommendations that are specifically linked to the event on April 20, 2010, and therefore do not attempt to anticipate future accident possibilities or consider the deep water drilling industry as a whole (Flournoy, 2011). This is an important distinction, as scholars have argued that reflexive documents rarely serve to increase safety within a sociotechnical system, as they merely serve to reinforce methods in preventing repetitive disasters of the same type or to demonstrate that something has been done about the disaster (Flournoy, 2011; Birkland, 2009). This reflexiveness, however, does not impede the goal of this thesis, which focuses on whether or not the accident could have been prevented within the existing sociotechnical system. Without such detailed documents that focus on the issues leading to the 2010 spill, I would not have had the data with which to conduct my analysis.

Chapter 4: Research Findings

The primary finding of this thesis is that the 2010 BP Deepwater Horizon spill was not preventable given the existing sociotechnical system. Based on a thorough analysis of the social and technical causes of the spill, and in accordance with the selected indicators and criteria, the Deepwater Horizon accident was the result of a moderate level of complex interactions and a significant level of coupling, resulting in a system accident. Further, the organizations in control of this technology were unable to cope with these characteristics due to an insufficient prioritization of safety, and an inadequate organizational culture within the sociotechnical system. The results of this analysis and a detailed explanation of each result are included in Appendix B, Figure 1 p. 91. A summary of these results is included below.

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
Concept Indicators 113	27	33	6	18	22	7
Percentage 100	23.9	29.2	5.3	15.9	19.5	6.2

Complexity and Coupling

In analyzing the causes of the 2010 spill in terms of normal accident theory concepts (complexity and coupling), the critical threshold to determine whether or not the accident was "normal" is the indication that at least 50% of the causes of the spill were conceptually linked to complexity or coupling. If the accident causes meet or exceed this threshold, it can be determined that the accident was very likely to happen due to the complexity and coupling within the system.

As seen in the above chart, the causal factors that led to the 2010 Deepwater Horizon blowout and spill can be described as exhibiting a moderate level of complexity (23.9%) and a significant level of coupling (29.2 %). That this accident can accurately be labeled a normal accident because complexity and coupling accounted for 53.1% of the concept indicators listed as causal factors of the spill within the sociotechnical system.

The system in question is complex in many ways, including technical interconnectedness, a reliance on indirect information sources, and unexpected interactions within processes, a large portion of which are attributable to the unpredictable environment in which deep water drilling takes place (U.S. Department of the Interior / BOEMRE, 2011). Deep water oil drilling is also a tightly coupled process, a characteristic that is largely a product of its process location which is on a vessel that is a hybrid between a nautical vessel and an oil derrick, complete with the immediate risks of the marine environment and highly combustible materials released under great pressure (U.S. Department of the Interior / BOEMRE, 2011). Other aspects of the deep water oil drilling process that lend themselves to tight coupling include tight drilling margins, a reliance on early and accurate detection of well 'kicks' and well flow, as well as the ability for combustible gas to trigger an explosion (U.S. Department of the Interior / BOEMRE, 2011)[14].

It is important to note, in consideration of the effect of coupling on the resulting accident, that many tightly coupled relationships that directly contributed to the blowout describe the

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[14] Perrow's 1999 publication features a visual representation of industries' relative degree complexity and coupling according to the author's assessment (Perrow, 1999: 97). As dictated by the findings to follow this paragraph, I have estimated a location on this chart that corresponds to the relative degree of complexity and coupling present within the Deepwater Horizon system at the time of the 2010 spill. This chart is featured in Appendix B, Figure 3, page 123.

interfaces between human operators and decision-makers and technology. Examples include the decision to use the mud gas separator during the blowout event, which was tightly coupled to the presence of gas on the rig and thus to the subsequent explosion (U.S. Department of the Interior / BOEMRE, 2011). Examples of the relationship also include mechanical signals that were missed or misinterpreted by operators, leading to catastrophe, such as the failure of the well crew to recognize the signs of a well kick in a timely manner and the collective misinterpretation of the negative test results. These two human failures are directly linked with mechanical failures triggering the blowout and explosion on the Deepwater Horizon (U.S. Department of the Interior / BOEMRE, 2011).

Reliability Factors

The goal of analyzing the causes of the 2010 spill in terms of high reliability theory concepts is to determine whether or not the organizational system (including BP, MMS, etc.) was performing as a high reliability organization. The critical threshold here is the indication that at least 10% of the causes of the spill were conceptually linked to the absence of a high reliability concept (organizational learning, safety prioritization, or organizational culture). If the accident causes meet or exceed this threshold, it can be determined that the accident was not likely to have been prevented or controlled by the organizational system because it was unable to function as a high reliability organization.

As seen in the summary chart on page 42, the identified causal factors can be described as being slightly attributed to a lack of organizational learning (5.3 %), however a lack of safety prioritization (15.9 %) and an inadequate organizational culture (19.5 %) were more significant factors in the 2010 spill. These results indicate that BP, its operating partners, and the Minerals Management Service were not functioning together as a high reliability system, and they collectively lacked two critical traits of high reliability, that of a prioritization of safety and an adequate organizational culture. This lack of reliability in the subject sociotechnical system greatly contributed to the cause of the 2010 spill.

There existed a cultural dominance of cost and production pressures that weighed in decisions made at all levels of power within BP[15] (Lustgarten, 2012: 22-23, 45,49), and was likely thoroughly instilled in operators and managers over time, as seen in the many decisions atop the Deepwater Horizon rig[16] (U.S. Department of the Interior / BOEMRE, 2011; Deepwater Horizon Study Group, 2011; Pritchard and Kotow, 2010). In this example of a profit conscious workplace culture, one could easily imagine that managers and operators were tacitly aware of cost and production pressures and may have felt pressured from company leaders to work outside the margins of safety to maintain a secure bottom line. Although litigation is still ongoing surrounding the 2010 spill, some reports indicate that this prevailing cost-conscious culture deeply impacted BP's ability to prevent the spill (*The Times-Picayune*, 2013).

The organizational structure controlling the operation of the Macondo well stands as an example of a collective failure to prevent, comprehend, or address risk within the sociotechnical system. The operations within the team on the Deepwater Horizon appeared to have a measure of

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[15] Some examples of this concept can be seen in the decisions implicated as causal factors in the 2005 explosion at BP's Texas City Refinery, as well as a 2006 leak of 212,000 gallons of oil in Alaska's North Slope from a BP maintained pipeline. Both of these events are detailed thoroughly in Lustgarten, 2012: 120-203.

[16] Some of these decisions include "not waiting for more centralizers of preferred design," "not running the cement evaluation log," and using lost circulation material as a spacer (listed in National Commission…, 2011c). These decisions all raised risk levels on the rig and saved time or operational costs (National Commission…, 2011c).

decentralization built into them (for emergent situations). However, as demonstrated by the existence of a “stop work order,” in which well operators could demand that work on a well be stopped if they feel work is contributing to an accident situation (U.S. Department of the Interior / BOEMRE, 2011). I argue, based on the above-cited examples, that cost and production pressures primarily and almost exclusively guided the actions of the operations team on the rig and their corporate counterparts in Houston.

Cost and production pressures are not unique to BP. Several authors have recognized a trend in hydrocarbon extraction firms toward riskier and more expensive technological processes, questionable financial reporting practices, and increased involvement with unreliable political regimes in search of “proved reserves” that is fiscally justified by rising oil prices (Coll, 2012: 50-56; Boman, 2012; Lustgarten, 2012:7-13, 52; National Commission…, 2011b). The connection between cost and production pressures and a decrease in safety buffers to large-scale accidents is clear in the case study of the 2010 Deepwater Horizon spill. This aligns with theories about safety within complex industries and specifically within the deep water drilling industry (Hofmann and Stetzer, 1996; Pritchard and Kotow, 2010; Perrow, 1994; Perrow, 1999: 118, 146, 175-176, 180; Heimann, 1993)

BP was undergoing a multitude of management changes and reassignments during the months leading up to the spill, thereby fragmenting and obfuscating responsibility, placing new operators in unfamiliar positions, and facilitating friction between operation leaders (U.S. Department of the Interior / BOEMRE, 2011). In addition to this managerial confusion, BP operated the Macondo well and Deepwater Horizon in collaboration with Transocean (its primary contractor), Halliburton, MI-SWACO, Schlumberger, and Sperry Drilling. This led to fragmentation of responsibility and a severe lack of communications between BP and its contractors (U.S. Department of the Interior / BOEMRE, 2011). Finally, operations surrounding the temporary abandonment of the Macondo well were woefully understaffed, thus distracting operators' attention from critical monitoring duties and pressing staff into multiple simultaneous duties. This eliminated operational capacity to address any unexpected events at the well (U.S. Department of the Interior / BOEMRE, 2011).

It should be noted that before the 2010 spill, BP generally regarded itself as a responsible, reliable organization, and touted its "Operating Management System" (OMS) as a significant step toward risk reduction (BP, 2006). The results of this analysis refute this assertion, and are accompanied by general opinion as expressed in an article by World Oil Online that asserted that BP's method of gauging safety and risk was flawed (World Oil Online, 2010).

Finally, the Minerals Management Service (now BOEMRE) clearly failed to prioritize safety in regulating deep water drilling processes at the Macondo well. Perrow in his normal accidents theory, notes that regulatory agencies operating under conflicting missions or objectives face difficulties in effectively enforcing safety laws[17] (Perrow, 1999: 157-159). The Minerals Management Service (MMS) was a prime example of this dilemma, and some authors assert that this stands as an example of regulatory capture (Flournoy, 2011; Sylves and Comfort, 2012; Plater, 2011). Many authors note that this organizational confusion is not completely remedied by the reorganization of BOEMRE (effectively splitting responsibility for lease sales

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[17] Perrow, in his 1999 publication, uses the example of air traffic controllers, whose conflicting missions are to decrease air collisions while increasing air traffic (Perrow, 1999: 156-158).

and promotion of deep water drilling away from enforcement duties by creating two entities that operate separately) (U.S. Department of the Interior / BOEMRE, “Reorganization…”). Because the United States relies heavily on hydrocarbon energy, a rational regulatory relationship that effectively keeps the oil producing industries in check may not be possible (Flournoy, 2011; Sylves and Comfort, 2012).

Finding 1: Inevitability of the 2010 Spill

Given the moderate degree of complex interactions and high degree of coupling, accompanied by the significant lack of safety prioritization and inadequate organizational culture within the subject sociotechnical system, one can conclude that the spill was not preventable. Not only did there exist sufficient complexity and coupling to cause a major accident within the system, but the social structure of control over this technology also severely failed to cope with this inherent danger through the prioritization of safety and creation of a culture of prevention. The primary research question is now answered, based on applying normal accident theory and high reliability theory to the data in the two selected reports: No, the oil spill was not preventable; it was a normal accident (for full analysis results, see p. 91). Further, BP and its operating partners and regulators did not exercise adequate vigilance in the form of safety prioritization and organizational culture to adequately cope with the complexity and coupling inherent in the subject sociotechnical system, thereby increasing the inevitability of the oil spill.

Finding 1a: Theoretical Applicability

Sub-question a) of this thesis posed the question “Do normal accident theory and high reliability theory apply to the 2010 BP oil spill?” In my selection of a theoretical framework to apply to this event, I considered a range of approaches. Many technical analyses of similar industrial accidents follow a root cause analysis or decision tree model to arrive at causal relationships in accident events (Leveson, 2004), while other theoretical approaches consider quantitative risk probability (Ji et. al., 2012). I chose to employ two methods of accident analysis, however, that were grounded in organizational theory, and therefore could qualitatively describe the technical and organizational characteristics leading to the oil spill. Both of these approaches are highly cited, as previously mentioned, and apply to a broad range of contemporary industrial accidents when employed together.

Although normal accident theory and high reliability theory are not without their faults, this thesis has used both theories in tandem in order to address many of these issues. Because normal accident theory lacks measurable indicators for cost and production pressures as well as organizational weakness, I have supplemented the indicators of complexity and coupling with those of organizational learning, safety prioritization, and organizational culture; drawn from high reliability theory. Similarly, because high reliability theory does not address inherent technical characteristics of a system that exist despite managements' best efforts, I have supplemented this theory with the indicators of complexity and coupling drawn from normal accident theory.

Although this thesis attempts to set forth criteria to measure the effect of these indicators on accident causation, the critique that normal accident theory and high reliability theory do not provide objective measurable criteria by which to judge the degree of their concepts within a system holds true. Because the concepts within both theories are somewhat ethereal, a concrete application of these concepts is difficult to establish. Further, this thesis does not fully resolve the larger issues of non-falsifiability inherent within both theories. This thesis does, however, aim to add to a developing body of work featuring measurable applications of normal accident theory and high reliability theory to events[18], with the intention to contribute to the formation of standard indicators and criteria by which to objectively analyze accidents within sociotechnical systems.

Finding 1 a (i): Theoretical Coverage

Based on my analysis of the causal factors of the 2010 spill, I can conclude that these two theories, employed simultaneously, effectively characterize a large majority of the causal factors in the spill. Out of the 113 concept indicators identified in the two reports, only 7 signified a concept outside of the realm of normal accident theory or high reliability theory. Of these concept indicators, 60 (53.1 %) signify complexity and coupling within the sociotechnical system, indicating that the oil spill was a normal accident. Further, 46 (40.7 %) of these concept indicators showed a lack of reliability within the organizations in charge of the Deepwater Horizon and Macondo well, which were incapable of coping with this degree of complexity and tight coupling within the system. These results are shown below.

Theory Applicability	Normal Accident	High Reliability	Other
Concept Indicators 113	60	46	7
Percentage 100	53.1	40.7	6.2

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[18] Wolf and Sampson have made significant progress in this endeavor with respect to normal accident theory – see Wolf, 2001 and Wolf and Sampson, 2007.

Finding 1 a (ii): Theory Symbiosis

Because the three most significant concepts implicated in the cause of the spill (coupling (29.2 %), lack of safety priority (15.9 %), and inadequate organizational culture (19.5 %)) are rooted in normal accident theory and high reliability theory, respectively, neither of these theories is sufficient to describe the 2010 spill when employed in isolation. For example, to describe the spill as simply a 'normal accident' with tight coupling and medium complexity (the meaning of "normal" as defined by Perrow) would miss significant organizational causes of the spill including cost and production pressures and a failure of management to adequately train operators to deal with loss of well control events. Similarly, to claim that the spill was singularly caused by a failure of management would be to ignore the uncertain environment and tight safety margins inherent in deep water drilling processes. For this reason, I contend that this application of both theories to the causal factors of the 2010 spill is necessary to describe both the technical and social factors that created a sociotechnical system unable to harness the destructive power of the Macondo well. The answer to sub-question 1a is yes; normal accident theory and high reliability theory are applicable to the Deepwater Horizon oil spill, however both of these theories are necessary to adequately describe the structural and organizational causal factors of the oil spill.

Finding 1 b: Indicators and Criteria

A thorough list of indicators and criteria used in this analysis are featured on pages 37-38. The indicators used to operationalize the concepts of normal accident theory and high reliability theories were numerous and easily recognized within the narratives of the accident reports. The criteria used in this analysis designated various degrees of influence of each concept, and were calibrated through an analysis of normal accident and high reliability theorists' application of their respective concepts to narratives of various accidents.

Many systems examined by Perrow (1999) feature either complexity or coupling in high degrees (43-57 % causal factors of accidents), yet do not have 'normal accidents.' This appears to be due to the fact that a 'normal accident' refers to an accident in which complexity and coupling are both signified in causal factors. Based on this argument, set forth by Perrow, I concluded that an accident can only truly be labeled a 'normal accident' if complexity and coupling (collectively) are linked to 50% or more of its identified causal factors.

I selected criteria to establish causal relationships between a lack of high reliability factors and the 2010 oil spill at a lower rate than that of normal accident theory based on the notion, asserted by high reliability theorists, that organizations must be constantly and impeccably vigilant to maintain reliability (La Porte and Consolini, 1991; Roberts, 1990b; Roberts and Bea, 2001). As a reflection of this assertion, I concluded that a lack of a high reliability concept linked to under 10 % of concept indicators could be considered a slight lapse in vigilance, while any connection higher than 10% represents a significant divergence from the tenets of high reliability.

In my analysis, I estimate that the applied indicators and criteria adequately gauge the effect of normal accident theory and high reliability theory concepts on causal factors of the 2010 spill. Because my criteria were drawn from narrative applications of these theories, however, further application of normal accident theory and high reliability theory concepts to similar disasters is needed to accurately set criteria for accident prediction.

Chapter 5: Policy Recommendations

The analysis contained in this thesis features two broad normative concepts by which to draft policy recommendations: technical accident potential and organizational capability to cope with risks (represented by normal accident theory and high reliability theory, respectively). The 2010 BP Deepwater Horizon oil spill stands as a clear example of a sociotechnical system with relatively high inherent accident potential combined with extremely poor organizational capability to cope with this risk. In this final section of this thesis, I urge policymakers to consider these two dimensions in technological accident prevention and in the construction of new regulations addressing deep water drilling.

Performance-Based v. Prescriptive Regulation

Studies conducted after the 2010 Deepwater Horizon spill concerned with regulatory action cite the examples of Norway and the U.K. in enacting "safety case[19]" requirements that place risk assessment duties in the responsibility of the operator of deep water drilling rigs (National Commission…, 2011a; Scarlett et. al., 2011). Safety case requirements are clearly more adaptive to different operations and exercise a performance-based method of regulation, as opposed to U.S. regulations which are largely prescriptive (Skogdalen and Vinnem, 2012). This method has been criticized, however, as "self-regulation" and runs the risk of eventually becoming a rote task performed by a small pool of contractors (National Commission…, 2011a). Further, some analysts have noted that, as valuable as a "safety case" requirement is in anticipating risk, this method may ignore the human and organizational factors in deep water

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[19] These "safety case" requirements refer to a comprehensive risk analysis required by Norwegian and U.K. regulators to be conducted and submitted by a drilling company. This system requires the company to assess all risks affiliated with the requested action and demonstrate risk reduction methods and response capacity to reach specific safety levels set by regulators. In this system, regulators oversee compliance with agreed upon methods set forth by the drilling company to maintain a low level of risk (Scarlett et. al., 2011).

drilling and may simply focus on technical safety barriers, which are in fact dependent on organizational capacity. One example is the engagement of safety barriers such as a BOP in a well control event, which is dependent upon human interpretation of signals of well kicks and flow, and therefore is rendered useless if not activated properly (Skogdalen and Vinnem, 2012).

Another issue with drawing a contrast between the U.S. and Norway or the U.K. is the wide gap in accident rates between countries that exercise the two methods. This gap is partially explained by deep water oil wells in the Gulf that are inherently more risky than those found elsewhere, largely because of their high pressure and high gas formations, which create slim drilling margins (Skogdalen and Vinnem, 2012). However, this gap is also likely due to the lack of required barriers against well blowout required by U.S. regulators in comparison to those in Norway (Skogdalen and Vinnem, 2012).

Changes to liability laws and permitting processes within BOEMRE have been suggested in the wake of the 2010 spill (U.S. Department of the Interior / BOEMRE, 2011; National Academy of Engineering and National Research Council, 2012; Peterson et. al., 2012; Galligan, Jr., 2012) and will help in addressing the issues presented by the 2010 Deepwater Horizon accident. But my results suggest that any regulatory change that does not address cost and production pressures by instituting strict safety standards and risk analysis (even at the risk of slowing operations and thereby production to the global market) will fail to enact real change in the deep water drilling industry. As indicated by my results, a certain level of complexity and coupling within the system of deep water drilling is unavoidable. However, organizational failures prompted by cost and production pressures increase the risk of accidents even further by reducing safety prioritization.

Deep Water Drilling in the Gulf of Mexico

Political forces weigh in all decisions in fuel production in the U.S., namely that of high powered lobbying forces pushing for looser regulation and the expansion of fossil fuel operations to increasingly risky and sensitive frontiers and a general lack of prioritization of development of alternative fuels for mass consumption (Plater, 2011). One major issue in the effective regulation of the oil industry lies in the fact that as oil prices increase, companies are incentivized to undertake increasingly risky and expensive operations to reach hydrocarbon formations that were previously untapped due to the prohibitive cost of extracting oil from them (Coll, 2012: 50-56; Boman, 2012; Lustgarten, 2012:7-13, 52; National Commission…, 2011b).

As drilling companies set their sights on the Gulf of Mexico and the Arctic (Handwerk, 2011), regulators will be hard pressed to prevent these new technologies from operating in increasingly hazardous frontiers that abut extremely sensitive ecological resources. Critics of the previous regulatory regime of MMS have noted that a revolving door between industry and regulators inhibited the power of the agency to demand increases in safety and may have impacted the quality of safety reviews (National Commission…, 2011a). Further, the severely deficient budget of MMS has clearly been a factor in preventing adequate regulatory capacity, indicating that an inability to offer competitive wages to regulators may create an imbalance in staff capability and lead professionals toward industry positions (National Commission..., 2011a.

Numerous reports surrounding the 2010 spill note that the hydrocarbon formations in the deep water of the Gulf of Mexico present unconquered challenges in terms of drilling margin and the intense pressure and heat at which its hydrocarbons circulate (Skogdalen and Vinnem, 2012; National Commission…, 2011d). This is the most critical technological problem in terms of regulating oil exploration in the Gulf of Mexico. The harsh environment and unique geologic formations of the Gulf of Mexico, coupled with the vast ecologically sensitive areas in the Gulf, upon which millions of residents depend directly and indirectly, leads to significantly more risk of failure and higher levels of catastrophic damage associated with accidents. The fact that the unique environment of the Gulf of Mexico presents this challenge invites the question of whether drilling in this unique environment can be regulated to a point of safety acceptable to society.

Liability

One important factor in the regulation of dangerous technologies is assigning and enforcing liability after an accident. Many have critiqued the National Resource Damage Assessment process (put forth by the OPA 90 laws) in the aftermath of the 2010 Deepwater Horizon spill, claiming that it is not suited for use in deep water spills and citing slow and conflicting processes that require the government and responsible party to agree on the validity of damage studies (Peterson et. al., 2012; NRDC, 2011). One issue to consider in addressing liability issues in deep water drilling is that of drilling firms' ability to pay liability assigned for spills.

Current laws require companies to prove that they are able to take on the financial liability to drill, however the current cap on financial liability allows small firms to enter the drilling field (National Commission…, 2011b). True liability reform should ideally ignore this barrier to entry and require verification that firms are not only financially able to cover the liability costs of a spill but also that these firms are physically equipped with the equipment and staff capacity to clean up spills quickly. Many authors have agreed with this approach, largely influenced by the relatively larger scale of hydrocarbons at risk of blowout in deep water drilling operations (Richardson, 2011; National Commission…, 2011b).

Public Participation

One suggestion applicable to the Gulf of Mexico is participation of those affected by spills through the use of a Regional Citizen Advisory Council (RCAC). This concept was hailed by Zygmunt Plater, the Chairman of the State of Alaska Oil Spill Commission's Legal Task Force, and put into place in Alaska following the 1989 Exxon Valdez spill to resolve the dipolar[20] system of regulation of the oil industry (Plater, 2011). These councils have assisted in advancing safety precautions in oil industry operations along the Alaska coast, and have facilitated whistleblowing from within the firms and government agencies (Plater, 2011).

Plater notes that because many residents of the Gulf coast are highly dependent on the waters of the Gulf for their livelihoods, these residents would have likely demanded more information and safety precautions from offshore drilling processes had they been allotted any measure of authority in the form of a citizen council (Plater, 2011). Although citizen participation is always an important factor in decision-making about natural resources, one

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[20] Plater's description of a "di-polar" system is one "where industry and government regulators come too close together, [and] responsible overall management of operations and risks suffers (Plater, 2011)." Plater further remarks that this type of system does not delegate any decision making power to residents affected by oil spills.

critical component of the effective operation of an RCAC is some form of legally allotted veto power or influence over dangerous activities, rather than simply providing citizens a sounding board through which to be heard. It should be noted, however, that this type of regulatory body would likely not assist in avoiding system accidents caused by inherent complexity and coupling, therefore rendering these councils useless against system errors and only effective against poor management practices and corporate influence.

Recommendation 1:

Restrain Gulf drilling to a specific quota or low level to be decreased yearly in order to phase out this highly accident prone operation. Continue the moratorium until reliance on hydrocarbons is decreased or until technological and organizational advancements in deep water drilling improve the ability to foresee and prevent loss of well control events.

Flournoy et. al. (2010) encourage technological advancement and less subsidization of deep water drilling in their recommendations based on the 2010 BP oil spill, however these authors do not directly urge for mass reduction in deep water drilling activities in the Gulf. Few authors urge the complete phasing out of this technology[21], likely due to the economic benefit that this technology provides. An application of normal accident theory to the 2010 oil spill, however, indicates that this event was a normal accident and was therefore unpreventable. Although technological advancements and stricter regulation may reduce some level of organizational failure and complexity within the subject system, it is not inconceivable that a similar chain of events could take place at another well site within the Gulf of Mexico. The only

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[21] U.S. Department of the Interior / BOEMRE, 2011 and Deepwater Horizon Study Group, 2011 are two prominent reports that do not recommend the phasing out of this technology.

way to truly reduce this risk is to phase out this technology that is inherently risky. Phasing out this technology would directly address the inevitability of another spill in the Gulf of Mexico.

Recommendation 2:

Adopt performance-based regulations similar to those exercised by Norway and the U.K.

Recommendation 2 (a):

These regulations should include requirements for multiple safety barriers against well blowouts.

Recommendation 2 (b):

These regulations should address the prevalence of contract workers in the deep water drilling industry through more effective labor laws and clear assignment of responsibility.

Scarlett et. al., 2011 as well as National Commission…, 2011a are two reports that recommend the adoption of performance-based regulations within the U.S. offshore oil regulations. This is an immediate solution that would address the lack of regulatory capacity within the Bureau of Ocean Energy Management. The adoption of a "safety case" requirement would likely encourage oil drilling companies within the Gulf of Mexico to practice increased organizational learning and may assist in fostering the prioritization of safety goals within the deep water drilling community. Ideally, these new regulations would include additional required barriers to well blowouts, as advocated by Skogdalen and Vinnem (2012). Finally, these new regulations should adequately address the assignment of responsibility within deep water drilling operators, specifically because many of these operations include numerous contractors under different managers, which can diffuse accountability (Deepwater Horizon Study Group, 2011; Rebitzer, 1995).

Recommendation 3:

Change the funding structure of BOEMRE in order to enable the agency to hire the highly trained professionals needed to adequately analyze industry information and conduct inspections.

As demonstrated by my analysis, the Bureau of Ocean Energy Management, Regulation, and Enforcement was not contributing to high reliability within the subject sociotechnical system. This agency clearly lacked an adequate organizational culture and the ability to prioritize safety and conduct organizational learning in April 2010. The addition of experts and adequate funding, as advocated in U.S. Department of the Interior / BOEMRE, 2011; Flournoy et. al., 2010; and Deepwater Horizon Study Group, 2011 would serve to address these issues.

Recommendation 4:

Remove the liability cap on oil spill claims made through the OPA 90 and Clean Water Act.

Changes to existing liability regulations as urged by Richardson, 2011 and National Commission…, 2011b may address the lack of prioritization of safety exemplified in the 2010 BP oil spill, by transferring a larger portion of the cost of oil spills directly to drilling companies and their insurers.

Recommendation 5:

Create and fund Regional Citizen Advisory Councils (RCACs) to oversee offshore drilling activities in the Gulf of Mexico with review powers over permitting processes, new proposals, and safety requirements specific to the Gulf of Mexico.

Plater (2011) recommends the introduction of RCACs to the Gulf of Mexico region to balance the competing needs of industry and the environment. The introduction of citizen concerns into the decision making process surrounding deep water drilling permits and proposals may increase the prioritization of safety within this organizational system, thus improving its reliability by considering the needs of those directly affected by oil spills.

Suggestions for Further Research:

Because deep water drilling regulations and permitting processes have undergone significant changes in the wake of the 2010 spill, I suggest that further study question whether post-spill changes to the sociotechnical system make catastrophic oil spills more preventable. A thorough application of the concepts of normal accident theory and high reliability theory to post-spill improvements would be enlightening. Accident reports, reports of near misses, and the operations of companies drilling within the Gulf of Mexico could be used as data. And the indicators utilized in this thesis may contribute to understanding the effectiveness of those changes.

Recommendation 6:

Apply normal accident theory and high reliability theory to similar accidents in order to cross-validate criteria. Employ additional methods such as multiple raters and tests of significance with non-parametric statistics to further hone the measurability and applicability of normal accident theory and high reliability theory concepts to actual events and organizations.

Chapter 6: Conclusion

The events of April 20, 2010 reminded the citizens of the United States that the nation’s ocean floor holds unbridled power that can overwhelm modern technology. This event also reminded the citizens of the Gulf Coast that a fearsome and risky endeavor takes place on their doorstep and can threaten their livelihoods, health, and property in an instant if not adequately controlled. Control, however, currently lies in the hands of imperfect organizations working within the margins of safety and profit which are, in some instances, regulated by a set of rules set in the past that are not adequately enforced in the present. Local residents feel this conflict between the harvesting of natural resources for export and the preservation of the economy and productive coastal ecosystem of the Gulf coast personally.

My analysis shows that the sociotechnical system controlling the Deepwater Horizon and the Macondo well on April 20, 2010 was indeed complex and tightly coupled, and further that this system was not organized optimally to respond to disaster risk. The system was hampered by cost and production pressures and was poorly guided by an ineffective regulatory regime. This event, in my estimate, fits the description of a system accident as outlined by normal accident theory and high reliability theory. A system accident portends more accidents of its kind in the future, granted sociotechnical conditions in the future meet these criteria. It appears that the Macondo well was not an anomaly in the Gulf of Mexico. It was similar to some other well sites in the region in terms of geologic demands and conditions for drilling. My analysis also shows that the organizational structure of the Deepwater Horizon could conceivably be adopted by other drilling rigs within the Gulf of Mexico, thus enabling missed well kicks and misinterpreted signals to taint what may otherwise be a safe drilling endeavor. Many factors signaling complexity, tight coupling, and organizational inadequacy within the 2010 BP system could be in widespread use, potentially creating a situation in which oil spills of a large magnitude in the Gulf of Mexico are not only possible, but more likely in the future.

Finally, I conclude that deep water drilling in this area should be restricted in order to reduce the catastrophic risk presented to the abutting communities and ecosystems, who do not proportionally benefit from such endeavors. In considering future lease sales and regulations for the outer continental shelf, lawmakers should consider the practical inevitability of future catastrophic oil spills and make decisions based on realistic qualitative risk rather than aspirational goals of failure-free operation.

Bibliography

The Associated Press. 2012. “Federal Judge Signs Off on $7.8 Billion BP Settlement.” *The Times-Picayune*, December 21, 2012. http://www.nola.com/news/gulf-oil-spill/index.ssf/2012/12/federal_judge_signs_off_on_78.html (accessed January 23, 2013).

Bain, William. 1999. “Application of Theory of Action to Safety Management: Recasting the NAT/HRT Debate.” *Journal of Contingencies and Crisis Management*, Volume 7, Number 3, September 1999, pp. 129-140. http://onlinelibrary.wiley.com/doi/10.1111/1468-5973.00106/pdf (accessed April 3, 2013).

Berninger, Jason, Spencer Williams, and Bryan Brooks. 2011. “An Initial Probabilistic Hazard Assessment of Oil Dispersants Approved by the United States National Contingency Plan.” *Environmental Toxicology & Chemistry*, July 2011, Volume 30, Issue 7, pp. 1704-1708. http://onlinelibrary.wiley.com.ezproxy.uno.edu/doi/10.1002/etc.532/abstract;jsessionid=0AEB55CEB635ACE7AAACDCC95852E349.d02t01 (accessed January 14, 2013).

Birkland, Thomas. 2009. “Disasters, Lessons Learned, and Fantasy Documents.” *Journal of Contingencies and Crisis Management*, Volume 17, Number 3, 2009, pp. 146-156. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?sid=140e4e8c-ae8f-

4fd7-b50a-918bb668107c%40sessionmgr112&vid=7&hid=117 (accessed January 30, 2013).

Boesch, Donald. 2010. "Winds of Change?" *The Washington Post Planet Panel*, May 6, 2010. http://views.washingtonpost.com/climate-change/panelists/donald_boesch/2010/05/winds_of_change.html (accessed March 3, 2013).

Boman, Karen. 2012. "Drillers See Robust Demand for Ultra-Deepwater Rigs." *Rigzone*, September 7, 2012. http://www.rigzone.com/news/oil_gas/a/120533/Drillers_See_Robust_Demand_for_Ultra Deepwater_Rigs (accessed January 21, 2013).

BP. 2006. "Sustainability Report, 2006" BP Website. http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/B/bp_sustainability_report_2006.pdf (accessed April 3, 2013).

Burns, Tom and G.M. Stalker. 1961. *The Management of Innovation*. New York: Barnes and Noble.

Cohen, Michael, James March, and Johan Olsen. 1988. "A Garbage Can Model of Organizational Choice." *Decisions and Organizations*, March 1988, pp. 294-334.

Coll, Steve. 2012. *Private Empire: Exxon Mobile and American Power*. New York: The Penguin Press, 2012.

Davis, Andrew. 2011. "Pure Economic Loss Claims Under the Oil Pollution Act: Combining Policy and Congressional Intent." *Columbia Journal of Law and Social Problems*, Volume 45, Number 1, 2011, pp. 1-44. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed January 30, 2013).

Deepwater Horizon Study Group. 2011. "Final Report on the Investigation of the Macondo Well Blowout." http://ccrm.berkeley.edu/pdfs_papers/bea_pdfs/dhsgfinalreport-march2011-tag.pdf (accessed January 30, 2013).

DeGravelles, John and J. Neale DeGravelles. 2011. "Symposium: Deep Trouble: Legal Ramifications of the Deepwater Horizon Oil Spill: The Deepwater Horizon Rig Disaster: Issues of Personal Injury and Death." *Tulane Law Review*, Volume 85, Issue 4, March 2011. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed January 23, 2013).

Flournoy, Alyson. 2011. "Learning from Disaster: Lessons for the Future from the Gulf of Mexico: Symposium Article: Three Meta-Lessons Government and Industry Should Learn from the BP Deepwater Horizon Disaster and Why They Will Not." *Boston College Environmental Affairs Law Review* Volume 38, Issue 2, pp.281-304. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed January 30, 2013).

Flournoy, Alyson, William Andreen, Rebecca Bratspies, Holly Doremus, Victor Flatt, Robert Glicksman, Joel Mintz, Daniel Rohlf, Amy Sinden, Rena Steinzor, Joseph Tomain, Sandra Zellmer, and James Goodwin. 2010. "Regulatory Blowout: How Regulatory Failures Made the BP Disaster Possible, and How the System Can Be Fixed to Avoid a Recurrence." The Center for Progressive Reform. http://www.progressivereform.org/articles/BP_Reg_Blowout_1007.pdf (accessed January 20, 2013).

Galligan, Jr., Thomas. 2012. "Blowout: Legal Legacy of the Deepwater Horizon Catastrophe: A Sad Tale of the Deepwater Horizon Disaster, Normal Accidents, and Our Appetite for Risk." *Roger Williams University Law Review*, Issue 17, Winter, 2012. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed January 30, 2013).

Gephart Jr., Robert. 1984. "Making Sense of Organizationally Based Environmental Disasters." *Journal of Management*, Volume 10, Number 2, pp. 205-225.

Goldstein, Bernard, Howard Osofsky, and Maureen Lichtveld. 2011. "The Gulf Oil Spill." *New England Journal of Medicine*, April 7, 2011, Volume 364, Issue 14, pp. 1334-1348.

Goode, Darren. 2010. "House, Senate Call for New Oil Spill Panel." *The Hill*, July 14, 2010. http://thehill.com/blogs/e2-wire/e2-wire/108779-house-panel-adds-call-for-new-oil-spill-commission (accessed March 3, 2013).

Handwerk, Brian. 2011. “The Next Prospects: Four Offshore Drilling Frontiers.” *National Geographic Daily News*, April 19, 2011. http://news.nationalgeographic.com/news/energy/2011/04/110418-future-of-offshore-drilling/ (accessed January 12, 2013).

Heimann, C.F. Larry. 1993. “Understanding the Challenger Disaster: Organizational Structure and the Design of Reliable Systems.” *The American Political Science Review*, Volume 87, Number 2, June 1993, pp. 421-435. http://www.jstor.org/stable/2939051 (accessed April, 11, 2012).

Henkel, Jessica. Bryan Sigel, and Caz Taylor. 2012. “Large-Scale Impacts of the Deepwater Horizon Oil Spill: Can Local Disturbance Affect Distant Ecosystems through Migratory Shorebirds?” *BioScience*, July 2012, Volume 62, Number 7, pp. 676 – 685. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=9&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=6 (accessed January 30, 2013).

Hofmann, David, and Adam Stetzer. 1996. “A Cross-Level Investigation of Factors Influencing Unsafe Behavior and Accidents.” *Personnel Psychology*, Issue 49, 1996, pp. 307-339. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=10&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=114 (accessed January 30, 2013).

Hopkins, Andrew. 1999. "The Limits of Normal Accident Theory." *Safety Science*, Volume 32 (1999) pp. 93-102.

Iaquinto, Christopher. 2012. "A Silent Spring in Deep Water?:Proposing Front-End Regulation of Dispersants After the Deepwater Horizon Disaster." *Boston College Environmental Affairs Law Review*, 2012, Volume 39, Issue 2, pp. 419-448. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed January 30, 2013).

Ji, Zhen-Gang, Walter Johnson, Zhen Li, Rebecca Green, S.E. O'Reilly, and Michael Gravois. 2012. "Oil Spill Risk Analysis: Gulf of Mexico Outer Continental Shelf (OCS) Lease Sales, Central and Western Planning Areas, 2012 – 2017, and Gulfwide OCS Program, 2012-2051." U.S. Department of the Interior, Bureau of Ocean Energy Management, May 2012. http://www.boem.gov/uploadedFiles/BOEM/Environmental_Stewardship/Environmental_Assessment/Oil_Spill_Modeling/2012-066-BOEM-OCS-Report.pdf (accessed January 30, 2013).

Johnston Jr., Allen, Laurel Calkins, and Margaret Cronin Fisk. 2012. "BP Spill Victims Face Economic Fallout Two Years Later." *Bloomberg News*. http://www.bloomberg.com/news/2012-02-23/bp-oil-spill-haunts-gulf-business-owners-almost-two-years-after-disaster.html (accessed February 24, 2013).

Jujasz, Antonia. 2012. "Investigation: Two Years After the BP Spill, A Hidden Health Crisis Festers." *The Nation*, April 18, 2012. http://www.thenation.com/article/167461/investigation-two-years-after-bp-spill-hidden-health-crisis-festers# (accessed January 23, 2013).

La Porte, Todd. 1994. "A Strawman Speaks Up: Comments on *The Limits of Safety*." *Journal of Contingencies and Crisis Management*, Volume 2, Number 4, December 1994, pp. 207-211. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=12&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=114 (accessed January 30, 2013).

La Porte, Todd and Gene Rochlin. 1994. "A Rejoinder to Perrow." *Journal of Contingencies and Crisis Management*, Volume 2, Number 4, December 1994, pp. 221-227. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=13&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=114 (accessed January 30, 2013).

La Porte, Todd and Paula Consolini. 1991. "Working in Practice But Not in Theory: Theoretical Challenges of 'High-Reliability Organizations.'" *Journal of Public Administration Research and Theory*, Volume 1 (1991):1, pp. 19-47.

Lee, Matthew and Troy Blanchard. 2012. "Community Attachment and Negative Affective States in the Context of the BP Deepwater Horizon Disaster." *American Behavioral Scientist*, January 2012, Volume 56, Issue 1, pp. 24-47. http://abs.sagepub.com.ezproxy.uno.edu/content/56/1/24.full.pdf+html (accessed January 30, 2013).

Leveson, Nancy. 2004. "A New Accident Model for Engineering Safer Systems." *Safety Science*, Volume 42, Number 4, April 2004, pp. 237-270.

Lin, Qianxin and Irving Mendelssohn. 2012. "Impacts and Recovery of the Deepwater Horizon Oil Spill on Vegetation Structure and Function of Coastal Salt Marshes in the Northern Gulf of Mexico." *Environmental Science Technology,* 2012, Volume 46, Number 7, pp. 3737-3743. http://pubs.acs.org.ezproxy.uno.edu/doi/abs/10.1021/es203552p (accessed January 30, 2013).

Lustgarten, Abrahm. 2012. *Run to Failure: BP and the Making of the Deepwater Horizon Disaster*. New York: W.W. Norton & Company, 2012.

March, James and Johan Olsen. 1979. *Ambiguity and Choice in Organizations*. Bergen, Norway: Universitetsforlaget, pp. 314-337.

National Academy of Engineering and National Research Council, Committee on the Analysis of Causes of the Deepwater Horizon Explosion, Fire, and Oil Spill to Identify Measures to

Prevent Similar Accidents in the Future, Marine Board, and Board on Environmental Studies and Toxicology. 2012. “Macondo Well Deepwater Horizon Blowout: Lessons for Improving Offshore Drilling Safety.” Washington D.C.: The National Academies Press, 2012. http://www.nap.edu/catalog.php?record_id=13273 (accessed January 30, 2013).

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (a). 2011. “A Competent and Nimble Regulator: A New Approach to Risk Assessment and Management, Staff Working Paper No. 21.” http://www.oilspillcommission.gov/sites/default/files/documents/A%20Competent%20and%20Nimble%20Regulator%20A%20New%20Approach%20to%20Risk%20Assessment%20and%20Management.pdf (accessed January 12, 2013).

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (b). 2011. “Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling: Recommendations.” January 2011. http://www.oilspillcommission.gov/final-report (accessed January 12, 2013).

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (c). 2011. “Macondo: The Gulf Oil Disaster, Chief Counsel’s Report.” http://www.oilspillcommission.gov/chief-counsels-report (accessed January 23, 2013).

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (d). 2011. “The History of Offshore Oil and Gas in the United States (long version), Staff Working

Paper No. 22." http://www.oilspillcommission.gov/sites/default/files/documents/HistoryofDrillingStaffPaper22.pdf (accessed January 23, 2013).

National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (e). 2011. "About the Commission." http://www.oilspillcommission.gov/page/about-commission (accessed February 24, 2013).

Natural Resources Defense Council. 2011. "The BP Oil Disaster at One Year: A Straightforward Assessment of What We Know, What We Don't, and What Questions Need to be Answered." April 2011. http://www.nrdc.org/energy/files/bpoildisasteroneyear.pdf (accessed January 12, 2013).

National Wildlife Federation. 2013. "How Does the BP Oil Spill Impact Wildlife and Habitat?" http://www.nwf.org/What-We-Do/Protect-Habitat/Gulf-Restoration/Oil-Spill/Effects-on-Wildlife.aspx (accessed February 24, 2013).

Perrow, Charles. 1994. "The Limits of Safety: The Enhancement of a Theory of Accidents." *Journal of Contingencies and Crisis Management*, Volume 2, Number 4, December 1994, pp. 212-220. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=17&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=114 (accessed January 30, 2013).

Perrow, Charles. 1999. *Normal Accidents: Living with High-Risk Technologies*. Princeton: Princeton University Press (first published by Basic Books, 1984).

Peterson, Charles, Sean Anderson, Gary Cherr, Richard Ambrose, Shelly Anghera, Steven Bay, Michael Blum, Robert Condon, Thomas Dean, Monty Graham, Michael Guzy, Stephanie Hampton, Samantha Joye, John Lambrinos, Bruce Mate, Douglas Meffert, Sean Powers, Ponisseril Somasundaran, Robert Spies, Caz Taylor, Ronald Tjeerdema, and Eric Adams. 2012. "A Tale of Two Spills: Novel Science and Policy Implications of an Emerging New Oil Spill Model." *BioScience*, Volume 62, Number 5, May 2012. http://www.aibs.org/bioscience-press-releases/resources/Peterson.pdf (accessed January 30, 2013).

Plater, Zygmunt. 2011. "The Exxon Valdez Resurfaces in the Gulf of Mexico… And the Hazards of 'Megasystem Centripedal Di-polarity'." *The Boston College Environmental Affairs Law Review*, Vol. 38, Issue 2, pp.391-416. Boston, MA: The Boston College Law School. http://www.lexisnexis.com.ezproxy.uno.edu/hottopics/lnacademic/ (accessed April 29, 2012).

Pritchard, David and Kenneth Kotow. 2010. "The New Domain in Deepwater Drilling: Applied Engineering and Organizational Impacts on Uncertainties and Risk." Deepwater Horizon Study Group and Successful Energy Practices International, LLC. http://ccrm.berkeley.edu/pdfs_papers/DHSGWorkingPapersFeb16-2011/NewDomainDeepwaterDrilling-

Applied%20Engineering%20_%20OrgainzationalImpacts-DMP_KJK_DHSG-Jan2011.pdf (accessed January 30, 2013).

Radder, Hans. 1992. “Normative Reflexions on Constructivist Approaches to Science and Technology.” *Social Studies of Science*, Volume 22, Number 1, February 1992, pp. 141-173. http://www.jstor.org.ezproxy.uno.edu/openurl?issn=0306-3127&volume=22&date=1992&issue=03063127&spage=141& (accessed January 30, 2013).

Reason, J. 1998. “Achieving a Safe Culture: Theory and practice.” *Work & Stress*, 1998, 12, pp. 293–306.

Rebitzer, James. 1995. “Job Safety and Contract Workers in the Petrochemical Industry.” *Industrial Relations*, Volume 34, Number 1 (January 1995), pp. 40-57. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=20&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=3 (accessed January 30, 2013).

Richardson, Nathan, Molly Macauley, Mark Chen, Robert Anderson, and Adam Stern. 2011. “Managing Risk Through Liability, Regulation, and Innovation: Organizational Design for Spill Containment in Deepwater Drilling Operations.” *Risk, Hazards, and Crisis in Public Policy*, Volume 2, Issue 2, Article 1, 2011.

Roberts, Karlene. 1990. (a) “Managing High Reliability Organizations.” *California Management Review,* 32 (4) pp. 101-113. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=22&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=3 (accessed January 30, 2013).

Roberts, Karlene. 1990. (b) “Some Characteristics of One Type of High Reliability Organization.” *Organization Science*, Volume 1, Number 2, pp. 160-176. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=23&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=3 (accessed January 30, 2013).

Roberts, Karlene and Robert Bea. 2001. “Must Accidents Happen? Lessons from High-Reliability Organizations.” *Academy of Management Executive*, August 2001 Volume 15, Number 3, pp. 70-78. http://www.jstor.org/discover/10.2307/4165761?uid=3739688&uid=2129&uid=2&uid=70&uid=4&uid=3739256&sid=21101844697563 (accessed January 30, 2013)

Rosa, E.A. 2005. “Celebrating a Citation Classic – and More.” *Organization & Environment*, 2005, 18, pp. 229–34. http://oae.sagepub.com/content/18/2/229.abstract (accessed January 30, 2013).

Rotkin-Ellman, Miriam, Karen Wong, and Gina Solomon. 2012. “Seafood Contamination After the BP Gulf Oil Spill and Risks to Vulnerable Populations: A Critique of the FDA Risk Assessment.” *Environmental Health Perspectives*, February 2012, Volume 120, Issue 2, pp. 157-161. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=24&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=109 (accessed January 30, 2013).

Sagan, Scott. 1993. *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton: Princeton University Press.

Sagan, Scott. 1994. “Toward a Political Theory of Organizational Reliability.” *Journal of Contingencies and Crisis Management*, Volume 2, Number 4, December 1994, pp. 228-240. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=25&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=109 (accessed January 30, 2013).

Salazar, Ken. 2010. “Decision Memorandum: Termination of the Suspension of Certain Offshore Permitting and Drilling Activities on the Outer Continental Shelf.” U.S. Department of the Interior (as archived by the *New York Times*). http://documents.nytimes.com/ending-the-deep-water-drilling-moratorium#document/p52 (accessed January 23, 2013).

Scarlett, Lynn, Igor Linkov, and Carolyn Kousky. 2011. “Risk Management Practices: Cross-Agency Comparisons with Minerals Management Service.” Resources for the Future Discussion Paper, January 2011. http://www.rff.org/RFF/Documents/DP-10-67.pdf (accessed January 30, 2013).

Schleifstein, Mark. 2012. “BP Oil Spill Medical Claims Settlement Covers Workers, Some Coastal Residents.” *The Times-Picayune*, April 18, 2012. http://www.nola.com/news/gulf-oil-spill/index.ssf/2012/04/bp_spill_medical_claims_settle.html (accessed January 23, 2013).

Schulman, P.R. 1993. “The Negotiated Order of Organizational Reliability.” *Administration and Society*, 1993, *25*, pp. 353–72. http://aas.sagepub.com/content/25/3/353.full.pdf+html (accessed January 30, 2013).

Shrivastava, Samir, Karan Sonpar, and Federica Pazzaglia. 2009. “Normal Accident Theory Versus High Reliability Theory: A Resolution and Call for an Open Systems View of Accidents.” *Human Relations*, Volume 62 (9), pp. 1357-1390. http://hum.sagepub.com.ezproxy.uno.edu/content/62/9/1357.full.pdf+html (accessed January 30, 2013).

Skogdalen, Jon Espen and Jan Erik Vinnem. 2012. “Quantitative Risk Analysis of Oil and Gas Drilling, Using Deepwater Horizon as a Case Study.” *Reliability Engineering and System Safety*, 100 (2012) pp. 58-66.

http://www.sciencedirect.com/science/article/pii/S0951832011002651 (accessed January 30, 2013).

Snook, S.A. 2000. *Friendly fire*. Princeton, NJ: Princeton University Press.

Sumaila, Rashid, Andres Cisneros-Montemayor, Andrew Dyck, Ling Huang, William Cheung, Jennifer Jacquet, Kristin Kleisner, Vicky Lam, Ashley McCrea-Strub, Wilf Swartz, Reg Watson, Dirk Zeller, Daniel Pauly, Terrance Quinn. 2012. "Impact of the Deepwater Horizon Well Blowout on the Economics of US Gulf Fisheries." *Canadian Journal of Fisheries & Aquatic Sciences*, March 2012, Volume 69, Issue 3, pp. 499-510. http://www.nrcresearchpress.com/doi/abs/10.1139/f2011-171#.UVzH5qW6Xww (accessed January 30, 2013).

Sylves, Richard and Louise Comfort. 2012. "The Exxon Valdez and BP Deepwater Horizon Oil Spills: Reducing Risk in Socio-Technical Systems." *American Behavioral Scientist* Volume 56, No. 1 pp. 76-103. Sage Publications. http://abs.sagepub.com/content/56/1/76 (accessed April 22, 2012).

Thomson Reuters Web of Science Social Science Citation Index Service. http://apps.webofknowledge.com.ezproxy.uno.edu/WOS_CitedReferenceSearch_input.do?product=WOS&SID=3AJplpe78@IHPiA6n6J&search_mode=CitedReferenceSearch (accessed February 25, 2013).

The Times-Picayune. 2013. “Tough Road Ahead for BP in Gulf Oil Spill Trial, Legal Experts Predict.” *The Times-Picayune*, March 1, 2013. http://www.nola.com/news/gulf-oil-spill/index.ssf/2013/03/tough_road_ahead_for_bp_in_gul.html (accessed April 3, 2013).

Turner, Barry. 1978. *Man-Made Disasters*. New York: Crane, Russak & Company, Inc.

Turner, B.A. and N.F. Pidgeon. 1997. *Man-made disasters*, 2nd edn. Oxford: Butterworth-Heinemann.

U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement. “Reorganization of The Bureau of Ocean Energy Management, Regulation and Enforcement.” www.boemre.gov (accessed January 19, 2013).

U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement. 2011. “Report Regarding the Causes of the April 20, 2010 Macondo Well Blowout.” http://docs.lib.noaa.gov/noaa_documents/DWH_IR/reports/dwhfinal.pdf (accessed January 30, 2013).

Vaughan, Diane. 1990. “Autonomy, Interdependence, and Social Control: NASA and the Space Shuttle Challenger.” *Administrative Science Quarterly*, Volume 35, Number 2, June, 1990, pp. 225-257. http://www.jstor.org/stable/2393390 (accessed April 11, 2012).

Vaughan, D. 2005. “System effects: On slippery slopes, repeating negative patterns, and learning from mistake?” In W. Starbuck & F. Moshe (Eds), *Organization at the limit: Lessons from the Columbia disaster*. Oxford: Blackwell, pp. 41–59. http://online.liebertpub.com/doi/pdfplus/10.1089/9780913113424.262 (accessed January 30, 2013).

The Wall Street Journal. 2010. “The Antidrilling Commission.” *The Wall Street Journa*l. http://online.wsj.com/article/SB10001424052748704895204575320892241446242.html (accessed March 3, 2013).

Weick, Karl. 1987. “Organizational Culture as a Source of High Reliability.” *California Management Review*, Volume XXIX, Number 2, Winter 1987, pp.112-127. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=30&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=6 (accessed January 30, 2013).

Weick, Karl. 1988. “Enacted Sensemaking In Crisis Situations.” *Journal of Management Studies*, Volume 25, Issue 4, July 1988, pp. 305-317.

Weick, Karl. 1990. “The Vulnerable System: An Analysis of the Tenerife Air Disaster.” *Journal of Management*, Volume 16, Number 3, 1990, pp. 571-593.

Wildavsky, Aaron. 1988. *Searching for Safety*. New Brunswick, NJ: Transaction Books.

Wolf, Frederick. 2001. "Operationalizing and Testing Normal Accident Theory in Petrochemical Plants and Refineries." *Production and Operations Management*, Volume 10, Issue 3, September 2001, pp. 292-305.

Wolf, Frederick and Paul Sampson. 2007. "Evidence of an Interaction Involving Complexity and Coupling as Predicted by Normal Accident Theory." *Journal of Contingencies and Crisis Management*, Volume 15, Number 3, September 2007, pp. 123-133.

Woodward, Joan. 1965. *Industrial Organization: Theory and Practice*. London: Oxford University Press.

World Oil Online. 2010. "Are You a Part of a High Reliability Organization?" World Oil News Center, World Oil Online Website. http://www.worldoil.com/HRO-ONS.html (accessed April 3, 2013).

Zuijdgeest, Alissa and Markus Huettel. 2012. "Dispersants as Used in Response to the MC252-Spill Lead to Higher Mobility of Polycyclic Aromatic Hydrocarbons in Oil-Contaminated Gulf of Mexico Sand." *PLoS ONE*, November 2012, Volume 7, Issue 11, Special Section pp. 1-13. http://ehis.ebscohost.com.ezproxy.uno.edu/eds/pdfviewer/pdfviewer?vid=33&sid=140e4e8c-ae8f-4fd7-b50a-918bb668107c%40sessionmgr112&hid=121 (accessed January 30, 2013).

Appendix A

Working Definitions

Working Definition of Complexity

Perrow uses a multifaceted definition of complexity in a sociotechnical system. In his section on complexity in his 1999 publication, Perrow indicates that "baffling interactions" indicate the presence of complexity and that this complexity is often present in systems that serve a diverse number of functions or that operate in "hostile environments" and are interconnected with other systems (Perrow, 1999: 72). Three main components of complexity within a system that Perrow identifies in his 1999 publication are multi-functionality[22], proximity[23], and indirect information sources[24] (Perrow 1999: 72-75). Perrow also notes that "transformation processes," those that "transform raw materials rather than fabricate or assemble them" are often a source of complexity, which is not easily addressed by traditional approaches to complex systems (aimed at making them more linear) such as better designs or operations (Perrow 1999: 84-85). Finally, in his analysis of complexity, Perrow lists characteristics that indicate complexity within a system including (Perrow, 1999: 85-86):

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[22] The common example of this characteristic is a "common mode" failure in which one component of a system is designed to conduct two processes, in which a failure of that component triggers two separate negative reactions, this is often exemplified by a heater which heats the gas in one tank while absorbing heat from a chemical reactor – if the heater fails, both the tank and the reactor will experience an unstable temperature– see Perrow 1999: 72-73 for more detail.

[23] Perrow's example of proximity as a characteristic in unforeseen interactions is that of an oil tanker accident in which flammable gases, engine equipment, and leaking oil combined to create a fire and explosion due to the proximity of oil storage near the engine room (Perrow 1999: 73-74).

[24] Indirect information sources may include sources of information that are not properly calibrated or do not measure parameters directly linked to critical information, or a reliance on gauges that replace visual observation of critical components (Perrow 1999: 73, 82-83).

- *Proximity of parts or units that are not in a production sequence;*
- *many common mode connections between components (parts, units, or subsystems) not in a production sequence;*
- *unfamiliar or unintended feedback loops;*
- *many control parameters with potential interactions*
- *indirect or inferential information sources; and*
- *limited understanding of some processes.*

In his discussion of complexity, Perrow also lists several qualities of linear systems including spatial segregation, "easy isolation of failed components," "less personnel specialization," and "extensive substitution of supplies and materials (Perrow 1999: 88)."

Sagan (1993) derives his definition from Perrow, noting that "Interactive complexity is a measure, not of a system's overall size or the number of subunits that exist in it, but rather of the way in which parts are connected and interact (Sagan, 1993: 78)." Sagan, in his consideration of a nuclear power plant, notes that proximity, a multitude of coordinated processes being conducted simultaneously, a limited understanding of some processes within the nuclear industry, and indirect information sources are all factors indicating complexity within a system (Sagan, 1993: 32-33).

Shrivastava et. al. (2009) echo Perrow's concept of complexity as signified by interactions that occur in unfamiliar, unplanned, or unexpected sequences; and which are either not visible, not comprehensible, have multiple functionality, the physical proximity of components, require specialized knowledge of personnel (Shrivastava et. al., 2009 note that this narrows operator's awareness of interdependencies), have multiple control parameters, and may require the deciphering of unfamiliar or unintended feedback loops (Shrivastava et. al., 2009).

Shrivastava et. al. add, however, that both complexity and coupling may be framed as dependent variables affected by the amounts of energy levels involved in the organization's transformative processes and the gaps in knowledge about the processes. These authors suggest that in analyzing the level of energy employed in a given transformative process, researchers also consider the number of "interfaces" at which point inputs and outputs are changed or monitored within complex systems (Shrivastava et. al., 2009). As asserted by Shrivastava et. al. (2009), my analysis of the relative complexity and tight coupling of the system surrounding the 2010 spill will include a consideration of the level of energy involved in the processes included in deep water drilling. Finally, Shrivastava et. al. (2009) also describe complexity as a dynamic element that is addressed through requisite variety of organizations (assigning adequate human capability to complex tasks).

In my consideration of the 2011 BOEMRE report, I have decided that any operation, process, or interaction that can be described by the above attributes of complexity will be considered an indication of complexity within the subject system.

Working Definition of Coupling

Perrow describes coupling generally as the level of responsiveness between two components in a system (Perrow, 1999: 90-91). Some facets of coupling that Perrow explores include time-dependent processes that may be utilized either for efficiency purposes or as necessitated by the materials used in a industrial process (such as chemical reactions), invariant sequences in production, sequences that may only be completed in one way (labeled as "unifinality"), and a lack of "slack" in a system (leaving little room for substitution of processes or materials) (Perrow, 1999: 93-94). Perrow notes that automatic safety devices are often featured in tightly coupled systems and must be "designed in" to protect against time-dependent failures that threaten the system and leave little room for human intervention in an emergency (Perrow, 1999: 94-95). As with his description of complexity, Perrow accompanies his description of tight coupling with a chart detailing the characteristics of tight coupling including (Perrow, 1999: 96):

- *Delays in processing not possible*
- *Invariant sequences*
- *Only one method to achieve goal*
- *Little slack possible in supplies, equipment, personnel*
- *Buffers and redundancies are designed-in, deliberate*
- *Substitutions of supplies, equipment, personnel limited and designed in*

In this discussion, Perrow also lists some qualities of loosely coupled systems which include such concepts as "processing delays possible," "order of sequences can be changed," and "slack in resources possible."

Sagan echoes these qualities of tight coupling and also notes that tight coupling "affects [a system's] ability to recover from small-scale failures before they cascade into larger problems

(Sagan, 1993: 34).” Sagan also contrasts the workings of a university, which may be complex but loosely coupling (allowing for scheduling changes and improvisation in reaction to errors) to that of a nuclear power plant, in which a small error may propagate within the system quickly with little slack for intervention or recovery (Sagan, 1993: 35-36).

Appendix B

Fig. 1: Causes, Contributing Causes, and Possible Contributing Causes Classified by Normal Accident Theory and High Reliability Theory Criteria

Note: all identified "Contributing Causes" are considered to be coupled to their respective effect, while factors labeled "Possible Contributing Causes" are considered to have a weaker linkage to subsequent events that cannot be unequivocally categorized as "coupling." Some factors are not clearly classifiable and signify multiple indicators of normal accident theory or high reliability theory.
* = Causal factor identified in U.S. Department of the Interior / BOEMRE, 2011
† = Causal factor identified in National Commission..., 2011c

Causes, Contributing Causes, and Possible Contributing Causes of the 2010 Spill

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
1. Cause of the Blowout: Failure of shoe cement*	X					
2. Contributing Cause: Decision to set the product casing in a laminated sand-shale zone in the vicinity of a hydrocarbon interval*	X	X				
3. Contributing Cause: Failure to take additional precautions during cementing considering known losses in the well*		X		X		
4. Contributing Cause: Failure to perform production casing cement job in accordance with API RP 65*		X				Divergence from accepted practices

Fig. 1 Continued

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
5. Contributing Cause: Decision to set float collar across the hydrocarbon-bearing zones of interest*		X				Divergence from accepted practices
6. Contributing Cause: Failure to inform all parties operating of the known risks associated with Macondo well operations*		X			X	
7. Contributing Cause: Failure to appropriately analyze/evaluate risks associated with well*	X	X		X		
8. Contributing Cause: Failure to place cement on top of wiper plug*		X	X			
9. Contributing Cause: Decision to use a float collar that was not sufficiently debris-tolerant*		X				
10. Possible Contributing Cause: Decision to set casing in the production interval with known drilling margin limits at total depth*				X		
11. Possible Contributing Cause: Lack of accurate and reliable flow-line sensors during cementing operations*	X					

Fig. 1 Continued						
Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
12. Possible Contributing Cause: Planning and conducting production casing cement job*	X			X		
13. Possible Contributing Cause: Failure of leaders and crew to recognize risks associated with multiple problems between 4/19-4/20*	X			X	X	
14. Cause of the Well Control Failure: Failure of crew to detect influx of hydrocarbons until they were above the BOP stack*	X	X			X	
15. Cause of the Well Control Failure: Crew's collective misinterpretation of the negative tests*	X	X			X	
16. Contributing Cause: Crew's inability to accurately monitor pit levels while conducting simultaneous operations during the critical negative test*		X		X	X	
17. Possible Contributing Cause: Failure to perform an incident investigation into 3/8/10 well control event and delayed kick detection*			X			

Fig. 1 Continued						
Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
18. Possible Contributing Cause: Failure to inform operators of all known risks associated with well production casing cement job*					X	
19. Possible Contributing Cause: Use of lost circulation material pills as a spacer*	X			X		
20. Possible Contributing Cause: Complacency of the crew*					X	
21. Possible Contributing Cause: Hafle's failure to investigate/resolve negative test anomalies*						Personal decision
22. Possible Contributing Cause: Failure of well site leaders to communicate well-related issues with managers on Deepwater Horizon*				X	X	
23. Possible Contributing Cause: Failure to provide complete and final negative test procedures in a timely fashion*	X		X	X		

Fig. 1 Continued

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
24. Possible Contributing Cause: Crew’s hesitance to shut-in the BOP immediately*	X	X			X	
25. Possible Contributing Cause: Failure to conduct the first of 2 negative tests*				X		Divergence from accepted practices
26. Possible Contributing Cause: Crew’s decision to bypass Sperry-Sun flow meter while pumping spacer overboard*	X		X	X		
27. Possible Contributing Cause: Failure of well control training and MMS requirements to address situations such as negative tests and displacement operations*	X				X	
28. Contributing Cause: Decision to use the mud gas separator during well control event*	X	X			X	
29. Contributing Cause: Ambiguity in Transocean well control manual on when to use diverter v. mud gas separator*	X	X			X	
30. Contributing Cause: Failure of bridge personnel to notify crew in engine room about alarms*		X			X	

Fig. 1 Continued						
Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
31. Possible Contributing Cause: Rig floor crew's inability to determine the location of the kick in relation to BOP stack and volume of hydrocarbons coming to rig*		X				
32. Possible Contributing Cause: Failure to initiate emergency disconnect system until after hydrocarbons were past BOP stack*		X				
33. Possible Contributing Cause: "Inhibited" general alarm system*						Divergence from optimal safety procedures
34. Possible Contributing Cause: Failure to train marine crew to handle serious blowout events*					X	
35. Contributing Cause: Location of air intakes for engine room #3 and 6*	X	X				
36. Contributing Cause: Failure of over-speed devices to initiate shut-down of engines*	X	X				

Fig. 1 Continued

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
37. Contributing Cause: Location /design of mud gas separator outlet vents*	X	X				
38. Contributing Cause: Failure to instruct engine room crew to initiate emergency shutdown sequence after receiving gas alarms*		X				Communication failure
39. Possible Contributing Cause: Classification of engine rooms #3 and #6 as non-classified areas*	X					
40. Possible Contributing Cause: Failure to identify risks associated with locating air intake of engine room #3 in close proximity to drill floor*	X					
41. Possible Contributing Cause: Absence of emergency shutdown devices that could automatically be triggered in response to high gas levels*	X	X				
42. Possible Contributing Cause: Failure to document which devices are tested *						Break in record-keeping

Fig. 1 Continued						
Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
43. Possible Contributing Cause: DP MODU operating philosophy when considering the performance of an emergency shutdown (ESD)*	X					
44. Cause of BOP Stack Failure: Failure of the BOP to shear the drill pipe due to physical location of pipe outside of the BSR cutting surface*	X					
45. Contributing Cause: Elastic buckling of the drill pipe *	X	X				
46. Possible Contributing Cause: Forces causing elastic buckling of the drill pipe*	X					
47. Contributing Cause: Failure of crew to stop work on the Deepwater Horizon*		X			X	
48. Contributing Cause: Failure to fully asses the risks associated with a number of operational decisions leading up to the blowout*		X		X		

Fig. 1 Continued

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
49. Contributing Causes: Cost or time saving decisions made without considering contingencies and mitigation*		X		X		
50. Contributing Cause: Failure to ensure all risks associated with operations were as low as reasonably practicable*		X		X		
51. Contributing Cause: BP's failure to have full supervision and accountability over activities associated with the Deepwater Horizon*		X			X	
52. Possible Contributing Cause: Failure to document, evaluate, approve, and communicate changes associated w/ DH personnel and operations*	X					
53. Possible Contributing Cause: Failure of BP and Transocean to ensure a common, integrated approach to well control*	X				X	

Fig. 1 Continued

Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
54. Possible Contributing Cause: Failure of current subpart O rule to identify personnel who need to be trained in well control operations, specifically in kick detection*					X	
55. Possible Contributing Cause: Conflict between managers and confusion about accountability at the managerial level†					X	
56. Contributing Cause: Failure to consult available experts on cement program and negative test procedures†		X			X	
57. Possible Contributing Cause: Failure of Transocean to communicate lessons learned on similar rig to BP†			X			
58. Possible Contributing Cause: Ineffective management and communication with contractors†				X	X	
59. Contributing Cause: BP use of incentives to promote performance †		X		X		

Fig. 1 Continued						
Causal Factor	Theoretical Characterization: NAT / HRT Concept					Other
	Complexity	Coupling	Lack of Org. Learning	Lack of Safety Priority	Inadequate Org. Culture	
60. Contributing Cause: MMS mission conflict†		X		X		
61. Contributing Cause: MMS lack of adequate precautions in permitting Macondo well site †		X	X	X		
62. Contributing Cause: Lack of adequate training for operators to monitor for well kicks as required by MMS†		X			X	
Concept Indicators 113	27	33	6	18	22	7
Percentage 100	23.9	29.2	5.3	15.9	19.5	6.2
Theory Applicability	Normal Accident		High Reliability			Other
Concept Indicators	60		46			7
Percentage 100	53.1		40.7			6.2

Explanation of classifications:

1. Report lists "contamination[25], over-displacement[26], and/or possibly nitrogen breakout[27]" as causes for the shoe track cement to fail. The crew would have been unable to directly observe these events (as they took place deep within the wellbore), and operators used

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[25] The materials pumped down a well to cement it are often separated to prevent their mixing and contamination, in the Macodo well, the crew pumped base oil, a water based spacer, a bottom dart, cement, a top dart, spacer, and drilling mud (in that order), in order to place the cement in the shoe track (the lowest portion of the wellbore). The 2011 report asserts that the drilling mud, which was oil based, may have mixed with and contaminated the cement mixture, thereby compromising the strength of the cement in the well (U.S. Department of the Interior / BOEMRE, 2011).

[26] The 2011 report notes that one possibility in the shoe track failure is that operators may have pushed the cement/mud/spacer mixture too far through the wellbore, thereby pushing the cement mixture past its intended location in the shoe track (U.S. Department of the Interior / BOEMRE, 2011).

[27] Nitrogen breakout refers to nitrogen bubbles in the foamed cement that "'break out' of suspension – which can result in inconsistent cement placement and densitites (U.S. Department of the Interior / BOEMRE, 2011)."

nitrified cement specifically to address the issue of lost returns in the well[28]. Contamination of the cement may have been an unexpected interaction, indicating complexity as well.

2. Although the 2011 report indicates that this is not a standard practice, the drilling team at the Macondo well's decision to set the production casing in a laminated sand-shale zone was partially motivated by the need to adapt to the uncertain environment in which the drilling took place. There was limited information on the hydrocarbon formation at the outset of the drilling activities at Macondo, and operators drilling the exploratory well were forced to end the well before its designed depth due to an increasingly slim drilling margin, which threatened the safety of the well. This change of plans left the shoe cement in a location where it was more prone to channeling or contamination (U.S. Department of the Interior / BOEMRE, 2011). This action was partially motivated by limited indirect information and adaptation to the unpredictable drilling environment, both signs of complexity. Additionally, this action was a contributing cause of the cement barrier failure within the well, and therefore was tightly coupled to this outcome (U.S. Department of the Interior / BOEMRE, 2011).
3. The 2011 report notes that the extreme mud losses within the Macondo well during drilling operations warranted additional caution during the production casing cementing operations, however it appears that BP failed to consider this fact and consistently made decisions based on cost and time savings, indicating a lack of prioritization of safety. The

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[28] "Lost returns" refers to the loss of drilling fluids into fissures in the geologic formation containing hydrocarbons, which was delicate at the Macondo well site and required special attention to maintaining the pressure balance required to control hydrocarbon flow while preventing large scale fracturing of the formation. The designers of the Macondo well used nitrified foam cement in this particular case in order to reduce the density of the cement in the well, thus lowering the risk of "formation breakdown." According to the 2011 report, this type of cement "presented technical challenges in ensuring that the cement mixture is stable (U.S. Department of the Interior / BOEMRE, 2011)."

decision not to take extra precautions has been identified as a contributing cause of the cement barrier failure and therefore was tightly coupled to this outcome (U.S. Department of the Interior / BOEMRE, 2011).

4. BP operators did not follow some of the recommended practices in API RP 65 (The American Petroleum Institute distributes industry standards and recommendations for oil drilling operations). This decision was identified as a contributing cause of the cement barrier failure, indicating tight coupling. While some of these actions may have been motivated by attempts to adapt to the delicate pressure balance within the well, this is clearly an example of a failure to conduct cementing procedures as instructed by accepted practices (U.S. Department of the Interior / BOEMRE, 2011).
5. BP's decision to set the float collar (one barrier to well inflow) across the hydrocarbon-bearing zones of the formation clearly went against standard practices and increased the coupling within the well operations by allowing less time for kick response by the crew by decreasing the "overbalanced" pressure condition between the cement and well pressures. This was a contributing cause of the cement barrier failure, and signifies tight coupling (U.S. Department of the Interior / BOEMRE, 2011).
6. The 2011 report indicates that BP personnel did not share information with their operating partners concerning the increased risks inherent in the Macondo well cementing job, although BP personnel were aware of some of these risks (U.S. Department of the Interior / BOEMRE, 2011). This is clearly a failure of communication with dire consequences, as this information may have aided in decision making by non-BP personnel. This failure in communication between partners indicates an inadequate

authority structure. This also signifies tight coupling as this action was a contributing cause of the cement barrier failure

7. As referred to in the body of this study, BP personnel clearly did not understand some of the risks associated with the Macondo well (such as those displayed by the OptiCem model), indicating complexity in accurate risk analysis, however BP personnel also made decisions to move ahead with cementing operations despite a lack of information on cement strength and float collar blockage, both of which increased risk but were not adequately accounted for in BP's calculations (which ignored the cumulative risk in the well operations) (U.S. Department of the Interior / BOEMRE, 2011). This lack of direct information signifies complexity within the system. This failure of interpretation was identified as a contributing cause of the cement barrier failure, indicating coupling (U.S. Department of the Interior / BOEMRE, 2011). Finally, this hastiness in neglecting risk analysis was likely driven by cost and production pressures, indicating a lack of prioritization of safety.
8. The 2011 report notes, "This additional cement would have created another barrier to prevent flow up the production casing… (U.S. Department of the Interior / BOEMRE, 2011)," indicating that the decision not to set cement on top of the wiper plug was not consistent with best practices in the industry. The fact that well site managers did not recognize the prudence in placing this barrier indicates organizational hubris within BP, signifying a lack of organizational learning, while this decision has been identified as a contributing cause of the cement barrier failure, indicating tight coupling.
9. The float collar was a critical component within the Macondo well, and its operation affected other processes within the well including the cement placement and well control

(U.S. Department of the Interior / BOEMRE, 2011). BP clearly made a faulty decision in failing to install a debris-tolerant float collar (U.S. Department of the Interior / BOEMRE, 2011), which had subsequent repercussions within the system by increasing coupling between components used to control well flow and eventually contributing to the cement barrier failure.

10. The 2011 report implies that production pressures may have played a part in this decision, as BP had the option to temporarily abandon the Macondo well without setting a production casing, which would have cost significantly more yet would have allowed more time for BP to draft a safer plan to extract hydrocarbons from the delicate well (U.S. Department of the Interior / BOEMRE, 2011). The fact that this action increased risk and was motivated by cost and production pressures indicates a lack of prioritization of safety.
11. Cementing operations were monitored through calculations and measurements with a high margin of error, indicating a reliance on indirect information sources – a clear sign of complexity within the system (U.S. Department of the Interior / BOEMRE, 2011).
12. BP and Halliburton made many decisions in conducting the cement casing job in the well that were motivated by accommodating the unique nature of the well, as well as reducing operation time and cost savings. (delicate pressure balance and material losses) (U.S. Department of the Interior / BOEMRE, 2011; National Commission.., 2011c). Many of these decisions increased complexity within the system as a response to the unstable environment and signified an inadequate prioritization of safety within the system.
13. There appears to have been a collective failure on the part of operators aboard the Deepwater Horizon to understand the well system as a whole and to place the

"anomalies" experienced at the site into the context of cumulative risk and uncertainty (U.S. Department of the Interior / BOEMRE, 2011). This represents complexity, in that operators could not comprehend the entire system and could not observe or comprehend certain interactions and oddities, however this also may indicate the presence of cost and production pressures that incentivized finishing the temporary abandonment procedures in as little time as possible, indicating a lack of prioritization of safety. Finally, the fact that operators were unable to adequately recognize and respond to anomalies, indicates a lack of adequate organizational culture within the system (U.S. Department of the Interior / BOEMRE, 2011).

14. This failure indicates complexity within the system, as crew would have had to monitor a variety of information sources to determine that a well kick was in progress (due to the usage of a multitude of mud pits during displacement operations – a situation that generally conflicts with industry accepted practices) (U.S. Department of the Interior / BOEMRE, 2011). This failure also highlights the tight coupling between flow into the well and a loss of well control, as the crew's ability to control an influx of hydrocarbons deteriorates quickly once the hydrocarbons are above the BOP stack (U.S. Department of the Interior / BOEMRE, 2011). Finally, this failure highlights the inability for BP and its operating partners to adequately staff the Deepwater Horizon with a crew large enough to effectively conduct displacement and monitoring processes simultaneously and to train the crew to react to a hydrocarbon influx adequately. This failure signifies complexity, coupling, and an inadequate organizational culture.
15. This causal factor indicates that negative test procedures are not clearly defined and generally agreed upon within the industry, indicating limited understanding of some

processes, which denote complexity within the system (U.S. Department of the Interior / BOEMRE, 2011). This factor also indicates a lack of adequate training or socialization as operators and managers were not instructed to dispute the results of the inconclusive negative test. Finally, the inability of the crew to correctly interpret the negative test directly contributed to the loss of well control, triggering the blowout and explosion. This failure signifies complexity, an inadequate organizational culture within the system, and coupling between misinterpretation of the test results and the blowout and explosion.

16. The crew's inability to accurately monitor pit levels during the critical negative test stemmed from the fact that the crew was conducting multiple processes aboard the rig while displacing drilling mud from the well riser, which obfuscated the signs of a kick. The crew also chose to bypass the Sperry-Sun flow-out meter, a critical measure of well flow, which inhibited their ability to detect a kick even further. Finally, it appears that managers atop the Deepwater Horizon failed to adequately delegate responsibility for kick monitoring. These decisions were largely motivated by an attempt to reduce operation time, and therefore signify a failure to prioritize safety, as well as a failure in organizational culture (U.S. Department of the Interior / BOEMRE, 2011; National Commission…, 2011c). This failure is also identified as a contributing cause of the kick detection failure, signifying coupling (U.S. Department of the Interior / BOEMRE, 2011).
17. The failure to investigate the March 8, 2010 well control event (U.S. Department of the Interior / BOEMRE, 2011) was a failure of management on the part of BP, and the fact that individuals present during the March 8 kick were also monitoring the Macondo well on April 20, 2010 (U.S. Department of the Interior / BOEMRE, 2011) is an example of

an organization failing to investigate and learn from accidents signifying a lack of organizational learning.

18. This appears to be a failure of communication between BP and its operating partners, however, like explanation #6, this may have contributed to the cause of the kick detection failure (U.S. Department of the Interior / BOEMRE, 2011) because this information may have increased operators awareness surrounding well kick monitoring activities. Because BP did not facilitate open communication with its partners, this is an example of an inadequate authority structure.
19. The use of lost circulation material pills as a spacer in the well represents complexity, as this decision created an unexpected interaction that obscured negative test results, however this decision was also motivated by cost pressures at the risk of safety, indicating a lack of prioritization of safety (U.S. Department of the Interior / BOEMRE, 2011).
20. The crew of the Deepwater Horizon became increasingly "comfortable" with the operations of the rig, which may have compromised their monitoring and decision making ability (U.S. Department of the Interior / BOEMRE, 2011). This likely spurred from a lack of a common safety culture.
21. This identified causal factor specifically focuses on the decision of one individual, indicating that this is a personnel matter and may have been partially a result of poor communication (U.S. Department of the Interior / BOEMRE, 2011).
22. This appears to be a symptom of a lack of open and free communication, however this failure may have partially resulted from decentralization in the organization, as well site leaders were not required to communicate their issues to their superiors in this instance,

(U.S. Department of the Interior / BOEMRE, 2011). Finally, the reluctance on the part of well site leaders to raise issue with the negative test results, and therefore confront more experienced engineers and managers about these results points to a desire to move forward with the temporary abandonment procedures quickly. This serves as a tacit motivation to place cost and production pressures ahead of safety concerns (National Commission…, 2011c). These factors indicate that this factor can be categorized as a sign of an inadequate authority structure and lack of prioritization of safety within the organization.

23. This failure may have resulted from differences of opinions within the industry on negative test procedures, as well as confusion surrounding operations stemming from disorganization (U.S. Department of the Interior / BOEMRE, 2011). The difference of opinion on negative test procedures exemplifies a limited understanding of some processes, an indicator of complexity, while the fact that BP rushed the preparation of the negative test plan and procedures even in light of hesitance raised by a manager who had experienced problems with "just in time delivery of well plans" indicates that the organization was unable to practice organizational learning or to prioritize safety over production pressures (National Commission…, 2011c). This factor signifies complexity, a lack of organizational learning and a lack of prioritization of safety.
24. This causal factor is likely owed to complexity, in that the crew had differing opinions about the cause of the anomalous occurrences surrounding the hydrocarbon influx. This failure also signifies tight coupling, however as the crew's quick response would have been necessary to intervene before the well blowout was well underway (U.S. Department of the Interior / BOEMRE, 2011). Finally, this failure is partially owed to

operator error, signifying a lack of adequate training and therefore an inadequate organizational culture. This failure signifies complexity, coupling, and an inadequate organizational culture.

25. This appears to have been a divergence from agree-upon industry accepted practices in deep water drilling. This decision, however, also went against the stated negative test procedures featured within the MMS approved permitting documents for the Macondo well site. This decision, based on communications between BP employees, appeared to have been motivated by at attempt to reduce operating time, signifying a lack of prioritization of safety. (U.S. Department of the Interior / BOEMRE, 2011).
26. This divergence from best practices limited the crew's ability to accurately monitor the volume of liquid leaving the well, and thus created unnecessary complexity while exposing organizational hubris in the failure to use an additional check against flow within the well (U.S. Department of the Interior / BOEMRE, 2011). The decision to bypass these critical flow meters may have been motivated by an attempt to save time during the displacement procedures, indicating a lack of prioritization of safety. This action also signifies complexity and a lack of organizational learning.
27. This failure indicates complexity in the possible ambiguity within the industry surrounding negative test and displacement operations. Failure by BP, Transocean, and MMS to guide operators adequately in safety precautions and risk prone well operations also signifies a inadequate training and thus a lack of adequate organizational culture (U.S. Department of the Interior / BOEMRE, 2011).
28. The crew's decision to use the mud gas separator may have been the result of a lack of knowledge about the volume of hydrocarbon flow from the well, which would depend on

inferential information sources (a sign of complexity), as well as a lack of training needed to adequately assess the condition as a blowout that would overwhelm the mud gas separator. This decision is also identified as a contributing cause of the response failure, indicating coupling (U.S. Department of the Interior / BOEMRE, 2011). This factor signifies complexity, a lack of adequate organizational culture, and coupling.

29. This causal factor may be owed to ambiguity within the industry (differing expert opinions – signifying complexity) concerning when to use the mud gas separator versus the diverter in a well control situation, however this is also an example of a lack of guidance and training provided by Transocean, indicating a lack of adequate organizational culture. Finally, this factor indicates coupling, as it was identified as a contributing cause of the response failure (U.S. Department of the Interior / BOEMRE, 2011). This factor signifies complexity, a lack of adequate organizational culture, and coupling.
30. This failure was likely prompted by a lack of emergency training exercises, as indicated by the testimony of Andrea Fleytas, an officer on the rig, signifying a lack of adequate organizational culture. This failure was also identified as a contributing cause of the response failure, indicating coupling (U.S. Department of the Interior / BOEMRE, 2011).
31. The rig floor crew's inability to determine the location of the kick in relation to the BOP stack and the volume of hydrocarbons coming to the rig signifies tight coupling, as the rig crew would have had a very short time period in which to make effective actions that would stop the chain of events that lead to the blowout. Because the crew lacked this information, they were unable to activate the BOP equipment in a timely fashion and

were unable to adequately decide whether or not to use the mud gas separator, and thus made decisions that lead to the ignition of flammable gas atop the rig (U.S. Department of the Interior / BOEMRE, 2011).

32. This is a clear example of tight coupling, as the emergent situation required quick response and was hampered by the influx of hydrocarbons above the BOP stack (U.S. Department of the Interior / BOEMRE, 2011).
33. The 2011 report correctly identifies this procedure as inconsistent with best practices (U.S. Department of the Interior / BOEMRE, 2011).
34. This factor indicates a failure on behalf of management to adequately train employees for emergency situations, which was made worse by a somewhat decentralized command structure leaving those who were not adequately trained in charge of emergency operations on the bridge of the Deepwater Horizon (U.S. Department of the Interior / BOEMRE, 2011). This failure represents a inadequate organizational culture structure that did not provide a common operating procedure.
35. The location of these air intakes to the outlet of the mud gas separator (which spewed combustible gas) is an example of complexity, specifically that of proximity of two components that later harbored an unforeseen interaction. This factor was also identified as a contributing cause of the Deepwater Horizon explosion, signifying coupling (U.S. Department of the Interior / BOEMRE, 2011).
36. The failure of the over-speed devices to shut down the engines on the Deepwater Horizon exemplifies complexity, as these engines were in proximity to the mud gas separator outlet and provided power to the rig in an emergency situation while posing an ignition risk. This failure also signifies tight coupling, however, as indicated by the presence of

automatic safety barriers which failed, leaving little time for human intervention. This failure was identified as a contributing cause of the Deepwater Horizon explosion, again signifying coupling (U.S. Department of the Interior / BOEMRE, 2011).

37. The location of the mud gas separator outlet vents, as alluded to previously, created an unforeseen complex interaction via proximity to combustion engines and sources of ignition. Further, this factor was identified as a contributing cause of the Deepwater Horizon explosion, signifying coupling (U.S. Department of the Interior / BOEMRE, 2011). This factor signifies complexity and coupling.
38. This failure indicates tight coupling, as the impending emergency situation would have required quick and decisive action to prevent injury, however this is also an example of poor communication between operators (U.S. Department of the Interior / BOEMRE, 2011).
39. The classification of the engine rooms as non-classified areas increased system complexity because it created an opportunity for ignition sources to be in close proximity to combustible gas in a blowout situation, relying only on over-speed devices to prevent engine failure. This interaction was clearly unseen by designers of the rig, however it created an environment conducive to an explosion on the Deepwater Horizon (U.S. Department of the Interior / BOEMRE, 2011).
40. This, like the previously mentioned factor, indicates complexity unforeseen by the designers of the Deepwater Horizon DP MODU (U.S. Department of the Interior / BOEMRE, 2011).
41. The absence of this safety device may have been motivated by the need for emergency power on the Deepwater Horizon in an emergency situation in order to escape the well

site; however this added complexity in the design of the rig, as emergency shutdown is necessary in an emergency that releases combustible gas in the vicinity of ignition sources. The manual engine shutdown mechanism also indicates tight coupling in the system as it requires human intervention at the immediate outset of a well control event releasing combustible gas to prevent the imminent interaction between the engines and gas (U.S. Department of the Interior / BOEMRE, 2011).

42. Neither Transocean nor the American Bureau of Shipping (ABS) were able to procure records tracking the testing of the over-speed devices on the rig engines due to inconsistent testing procedures (U.S. Department of the Interior / BOEMRE, 2011). This is clearly a failure to keep orderly documentation of inspection and may indicate a failure in inspection processes in general.
43. This "operating philosophy" refers to the conflicting needs experienced on a DP MODU which include the need to shutdown engines on the rig to avoid the risk of igniting combustible gas versus the need to power the rig in a blowout or emergency situation in order to disconnect from the well string and evacuate the well site. These conflicting demands indicate complexity within the system surrounding the engines, which serve a critical purpose but pose a risk while serving this purpose (U.S. Department of the Interior / BOEMRE, 2011).
44. A primary cause of the Deepwater Horizon blowout was the inability of the BOP to sever and seal the drill pipe, which was lodged in-between the faces of the blind shear ram outside of the area of the cutting surface. This is an example of an unexpected interaction between parts, signifying complexity (U.S. Department of the Interior / BOEMRE, 2011).

45. Unforeseen interactions between the well equipment caused the drill pipe connected to the Macondo well and the Deepwater Horizon to buckle and become trapped between the blind shear ram faces, thus disabling the blind shear ram (part of the BOP) from severing and sealing the well pipe. The 2011 report indicates that two possible scenarios may have caused this buckling:

    a. "Flow from the well forced the section of drill pipe located between the closed VBR [variable bore rams] and the closed upper annular up into the closed upper annular to a point where a tool joint stopped against the closed upper annular. Wellbore conditions produced enough force to cause the pipe to elastically buckle in this area."
    b. "Flow from the well and weight of the unsupported 5,000 feet of 6 5/8 inch diameter drill pipe above the closed VBR forced the section of drill pipe located between the upper VBR and the upper annular into an elastically buckled state (U.S. Department of the Interior / BOEMRE, 2011)."

    These chains of events were clearly unforeseen and prevented the BOP from working correctly, indicating complexity and coupling within the system.

46. See above, indicating complexity.
47. The operators on the Deepwater Horizon were authorized to issue a "stop work" order if they believed that the operations as conducted posed significant danger to the crew. The fact that these workers were authorized to make this command but did not in the face of clearly risky operations that were contrary to standard practices (that of utilizing multiple mud pits in displacement operations) indicates that the attempt to decentralize authority by allowing operators close to the system some measure of control over its operation did

not serve the purpose of preventing the 2010 blowout, possibly because cost and production pressures were ingrained in the organizational culture at the site. This failure to stop the work at the site is considered a contributing cause of the Macondo Blowout, signifying coupling (U.S. Department of the Interior / BOEMRE, 2011).

48. This appears to be a failure of management motivated by cost and production pressures, as portrayed in the 2011 BOEMRE report, indicating a lack of prioritization of safety. This failure, however, was also a contributing cause of the Macondo Blowout, and therefore is coupled to the chain of events that became this accident (U.S. Department of the Interior / BOEMRE, 2011).

49. The 2011 report asserts that BP managers made a number of decisions that may have increased risk on the Deepwater Horizon without regard to contingencies and mitigation in the days leading up to the 2010 spill. These decisions appear to be strictly motivated by cost and production pressures, and are examples of a lack of prioritization of safety. These decisions also signify coupling within the system as they are identified as contributing causes of the Macondo Blowout (U.S. Department of the Interior / BOEMRE, 2011).

50. The management of the Deepwater Horizon clearly did not attempt to reduce risk inherent in the drilling system to a level as low as reasonably possible, as a prioritization of safety would require. This failure is also identified as a contributing cause of the Macondo Blowout, indicating coupling (U.S. Department of the Interior / BOEMRE, 2011).

51. Supervision and accountability on the Deepwater Horizon was fragmented and BP did not effectively manage the operations on the rig, indicating an inadequate organizational

culture. The 2011 report insists that this created a chaotic environment and was a possible contributing cause of the blowout. Further, this factor is identified as a contributing cause of the Macondo blowout, indicating coupling (U.S. Department of the Interior / BOEMRE, 2011).

52. A number of personnel changes occurred in the management and staffing of the Deepwater Horizon shortly before the 2010 blowout, including the reorganization of some departments controlling the planning and temporary abandonment of the well. This indicates organizational complexity in the system controlling the well, and displays a temporary weakness in the system as many employees were still settling into their new roles. Similarly, the operations aboard the Deepwater Horizon were changed and amended with little notice during the temporary abandonment procedures due to unforeseen circumstances and changes in the order of procedures as dictated by operators and engineers. This signifies complexity in the system controlling the Deepwater Horizon (U.S. Department of the Interior / BOEMRE, 2011).
53. The failure of Transocean and BP to establish common well control guidelines indicates that blowout situations are dealt with differently between different firms. Because few well control situations are exactly alike, it appears that this event is complex, and required pre-considered guidance for operators. The failure of these two companies to communicate clear guidelines to their employees indicates an inadequate organizational culture (U.S. Department of the Interior / BOEMRE, 2011).
54. The failure of BP's Subpart O plan to specifically identify some operators with responsibility for well monitoring, specifically kick detection, indicates an organizational system with diffuse allocations of responsibility for crucial functions in the drilling

system. This scenario signifies an inadequate organizational culture. (U.S. Department of the Interior / BOEMRE, 2011).

55. Like the previous factor, the presence of unclear or diffuse accountability was a widespread problem within the BP management following a recent reorganization. This, as well as personal conflicts between managers, caused confusion at the well site, leading to a dysfunctional organizational culture (National Commission…, 2011c).
56. BP managers and well site leaders failure to adequately consult available experts concerning the casing design and negative test procedures is a clear indicator of an inadequate organizational culture (National Commission…, 2011c). The decision not to consult these experts had immediate repercussions as seen in the subpar performance of the cement and the incorrect interpretations of the negative test results by those on the rig. This failure can be seen as a contributing cause of the cement bond failure.
57. Transocean had recently experienced a well control event during displacement procedures, a similar experience to that of the later Deepwater Horizon accident. Although this experience heightened awareness and vigilance within Transocean concerning this procedure, this information was not shared with BP employees, thereby preventing organizational learning between the two partners (National Commission…, 2011c).
58. BP failed "to effectively manage the timeline and validity of the cement testing" process by Halliburton. Halliburton also failed to "effectively communicate cementing issues to BP." In this respect, it is clear that communication between the two partners was not open and responsive to issues, indicating an inadequate organizational culture between the two entities (National Commission…, 2011c). A possible reason for a lack of oversight over

the cement testing procedures as conducted by Halliburton may have been production pressure experienced by BP, as asserted in National Commission…, 2011c. This notion of cost cutting and rushing production is directly linked to many subsequent decisions by BP surrounding the Macondo well that may have increased risk. This is indicative of a lack of prioritization of safety and an inadequate organizational culture.

59. The operating style of BP featured strong incentives for reducing cost and promoting production efficiency, which may have been promoted at the expense of safety, urging some managers to "treat redundancies as inefficiencies." This is a clear example of a lack of prioritization of safety within the system and is coupled to many other decisions and actions leading to the 2010 spill (National Commission…, 2011c).
60. The conflict between the two tasks of MMS (promoting and regulating offshore exploration) was a direct contributor to the way in which BP approached well safety, design, and processes at the Macondo well. This lack of clear prioritization of safety on behalf of MMS is coupled to a lack of safety prioritization within BP (National Commission…, 2011c).
61. The permitting procedure for BP to commence drilling and temporarily abandoning the Macondo well was not adequately rigorous, and therefore demonstrated a lack of adequate oversight by MMS. The Chief Counsel's Report on the 2010 spill drafted by the National Commission on the BP Deepwater Horizon Spill and Offshore Drilling lists numerous examples of permit requirements or policies that were overlooked or waived by MMS in reference to the Macondo well site. Some decisions, like allowing BP to set the cement surface plug deeper than standard requirements dictated, were made quickly with little evident consideration of overall risk, and may have directly contributed to the spills

occurrence (National Commission…, 2011c). The Chief Counsel's Report makes a thorough case for the fact that MMS not only failed to apply adequate safety requirements to BP in this case, but generally neglected to keep regulatory pace with technological advances in deep water drilling (National Commission…, 2011c). The fact that this agency failed to address serious safety concerns and adjust its procedures in response to new technology indicates that it failed to practice organizational learning or safety prioritization. The fact that these failures were likely linked to the lax safety precautions in the design of the Macondo well and temporary abandonment procedures also points to coupling within the system (National Commission…, 2011c).

62. Regulations covering drilling activities on the Deepwater Horizon required that operators responsible for well kick monitoring complete a form of "MMS-approved well control training." This training, however proved inadequate due to its focus on well kick response during drilling operations not during temporary abandonment (National Commission…, 2011c). This lack of adequate training as mandated by MMS was a failure on the part of the regulatory regime to instill a common set of operating procedures in the workforce directly responsible for monitoring for well kicks, indicating an inadequate organizational culture within the system. Further, this failure was likely a contributing cause of the well operators at Macondo to recognize a well kick until it was thoroughly underway, leading to the blowout. This is an example of coupling.

Fig. 2 Calibration of Normal Accident Criteria based on Perrow's (1999) Analyses (Perrow, 1999: 98-99, 232-241

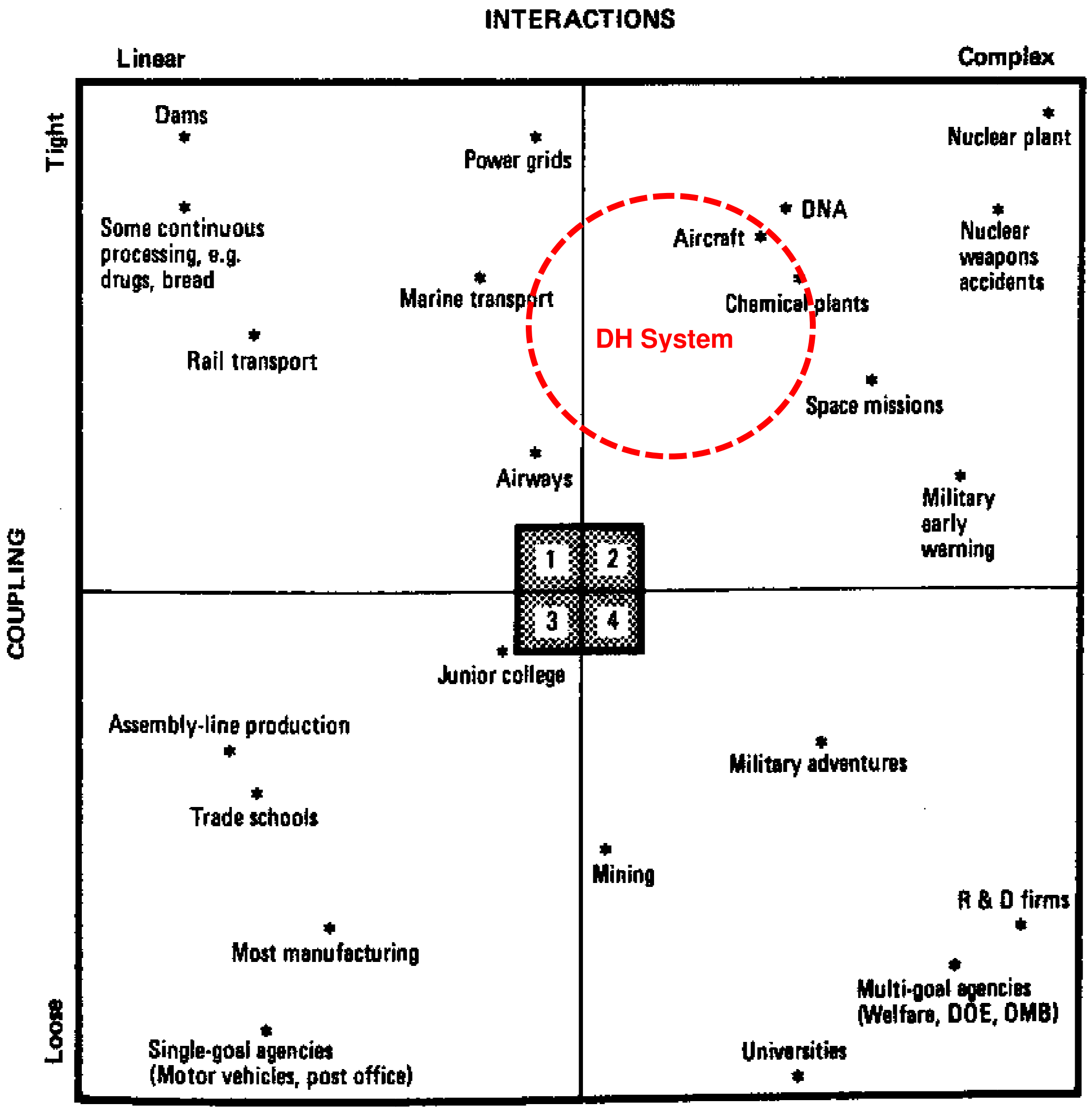
University Dispute Over Tenure – Example of Complexity		
Causal Factor	Signifies Complexity	Other
Decision to deny tenure to teacher		X
Quality of service program	X	
Dismissal linked to service program		X
Student protest		X
Creation of evaluation program	X	
Application of program to other teachers	X	
Unexpected demands	X	
Total Factors 7	4	3
Percentage 100	57.1	42.9

Grand Teton Dam Failure – Example of Tight Coupling		
Causal Factor	Signifies Coupling	Other
Failure in one part of dam linked to structural integrity of the whole	X	
Critical dam failure linked to destruction	X	
Connection between dam failure and earthquakes	X	
Failure in inter-agency communication		X
Lack of action taken concerning known risks	X	
Agency relationships inspired complacency		X
Investment in dam		X
Risk data ignored	X	
Cracks in dam structure downplayed	X	
Institutional hubris		X
Dam filled too quickly	X	
Unpredictable environment		X
Failure to recognize anomalies/signs of danger		X
Failure to adequately inspect dam construction		X
Professional differences concerning connection between earthquakes and reservoirs		X
Scale of the dam		X
Proximity of dam to human settlements	X	
Levels of potential energy produced by dam containment	X	
Faulty data analysis		X
Total Factors 19	9	10
Percentage 100	47.4	52.6

Note: Neither of these events are considered a normal accident by Perrow.

Fig. 3 Approximate Location of BP Deepwater Horizon on Perrow's Interaction / Coupling Chart (Perrow, 1999:97)

FIGURE 3.1
Interaction/Coupling Chart



Explanation of Placement:

I have chosen to locate deep water drilling in the Gulf of Mexico in the Interaction / Coupling Chart in the upper right quadrant of the chart (indicating that this process features moderate complexity and tight coupling) based on the results of my analysis of the concept indicators identified in causal factors of the oil spill (p. 88). Based on Perrow's analysis of a dam failure and university's dispute with students concerning tenure, I have concluded that if 50 % of an accidents causal factors can be linked to a concept indicator within normal accident theory (complexity or coupling), this system can be described as exemplifying a high level of the indicated quality. This 50 % relationship is employed as the upper bound of concept expression within the analyzed systems. Because the Deepwater Horizon system exemplified a moderate degree of complexity shown by 23.9 % of its concept indicators and a significant degree of coupling shown by 29.2 % of its concept indicators, this system occupies its above designated area.

This location is near "Aircraft" (the operation of aircraft, not to be confused with airways control) and "Chemical plants." This region corresponds to the Deepwater Horizon system because deep water drilling is similarly tightly coupled and complex as that of the aircraft industry because it takes place in an unforgiving environment.[29] The Deepwater Horizon system is also located in a position near that of a chemical plant because both of these processes include specific control parameters of high temperature, high pressure, and massive releases of energy. It should be noted that although the Deepwater Horizon system is similar to marine transport in that it took place on a marine craft (a DP MODU), the processes of extracting hydrocarbons from

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[29] Deep water drilling occurs at sea, where accidents may not always cause the rig to sink and may lend more opportunities for human intervention in a time of crisis, as opposed to in high altitudes, in which mishaps can result in the crashing of the aircraft. Perrow discusses the airline industry in pages 121-146 of his 1999 publication.

a deep water well significantly increase the complexity and slightly increase the coupling above those levels experienced in marine transport[30].

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[30] The demands on a mobile marine drilling rig are not simply those of staying afloat in a harsh environment, but also consist of controlling massive underground pressure and storing and transferring large quantities of liquid from the rig to the well and vice versa (U.S. Department of the Interior / BOEMRE, 2011). Perrow discusses the marine transportation industry in pages 171-223 of his 1999 publication.

Fig. 4: BP Decisions and Associated Cost, Time and Risks (recreated from U.S. Department of the Interior / BOEMRE, 2011)

BP Decisions and Associated Cost, Time and Risks

BP Decision	Less Cost to BP	Less Rig Time	Greater Risk
6 versus 21 centralizers	Yes	Yes	Yes
Cement bond log	Yes	Yes	Yes
Full Bottoms Up on 4/19	Yes	Yes	Yes
Long String versus Liner	Yes	Yes	--
Timing of Lock Down Sleeve Installation After the Negative Test	Yes	Yes	Yes
Pumping mud to boat while displacing	Yes	Yes	Yes
Lost Circulation Material ("LCM") pills combined for Spacer	Yes	Yes	Unknown

Contextual description of each listed BP Decision

1. <u>6 versus 21 centralizers</u>

   The 2011 report defines centralizers as "pieces of equipment used to keep the casing centered in the well (U.S. Department of the Interior / BOEMRE, 2011)." These allow cement to be installed evenly surrounding the well casing in the well bore, and therefore are crucial to the structural integrity of the cement job in a well. During the cement modeling stage, Halliburton employees modeled a number of well construction techniques and situations in order to find the optimal method of cementing and temporarily abandoning the Macondo well. These models showed that with 10 centralizers, cement channeling was possible and was accompanied by a "moderate" gas flow potential, while with 21 centralizers, channeling would not occur and gas flow potential was minor (U.S. Department of the Interior / BOEMRE, 2011). BP managers were clearly aware of the results of this modeling, as demonstrated by their request for 15 additional centralizers, however operators decided not to install these centralizers at the well cementing phase because they incorrectly perceived them to be the incorrect types of centralizers for the job (U.S. Department of the Interior / BOEMRE, 2011; Deepwater Horizon Study Group, 2011).

2. <u>Cement bond log</u>

   A cement evaluation log is a common element of a well cementing procedure such as that conducted by the Deepwater Horizon crew, in order to anticipate fluid losses during the casing cement job and to verify the strength of the cement placement. During the temporary abandonment procedures of the Macondo well, however, BP employees checked the integrity of the cement by checking "lift pressure" and evaluating if there had been apparent fluid losses. Based on these tests, Mark Hafle, a leader in the operation, then decided that a cement log was unnecessary and sent the logging crew home (U.S. Department of the Interior / BOEMRE, 2011).

3. <u>Full Bottoms Up on 4/19</u>

   A "full bottoms up" refers to a process in which the operators on a rig in charge of cementing the well circulate drilling mud through the well casing in order to 1) clean out the well and 2) analyze any material circulated from the bottom of the well in order to determine if hydrocarbons are present (U.S. Department of the Interior / BOEMRE, 2011). In the cementing process of the Macondo well, however, operators decided not to conduct a full bottoms up circulation due to concerns about lost returns (fluids lost into the formation), which they had previously experienced with the well (U.S. Department of the Interior / BOEMRE, 2011).

4. Long String versus Liner

   In considering the design of the Macondo well, BP was faced with two options to cement the well for temporary abandonment, the liner with tieback and a long string design. Although there are many strengths and weaknesses associated with both designs, BP ultimately chose the long string design, however this decision increased risk, according to many reports, and was influenced at least partially by cost savings and reduced installation time (U.S. Department of the Interior / BOEMRE, 2011; Deepwater Horizon Study Group, 2011). It should also be noted that BP leaders had a third option to consider in the temporary abandonment procedures, that of abandoning the well with no production casing installed in order to reassess the plan of action in designing the well, a procedure which is often utilized in wells with little drilling margin(U.S. Department of the Interior / BOEMRE, 2011). This third option, although likely safer, would have cost considerably more (U.S. Department of the Interior / BOEMRE, 2011).

5. Timing of Lock Down Sleeve Installation After the Negative Test

   The 2011 report notes that a lock-down sleeve holds the production casing (the tube through which the rig extracts hydrocarbons) to the wellhead during production (against the pressures generated by well flow) (U.S. Department of the Interior / BOEMRE, 2011). The report indicates that although it was not originally planned to install the lock-down sleeve, the crew of the Deepwater Horizon were instructed to install this equipment upon BP leaders discovering that this installation would save time and money if conducted by the Deepwater Horizon (U.S. Department of the Interior / BOEMRE, 2011). Simply put, the decision to set the lock-down sleeve during temporary abandonment was unnecessary and increased risk by demanding operators to conduct a procedure that they had little experience with and necessitating a deeper setting of the surface plug within the well, which contributed to the severe pressure differential in the well during displacement procedures, directly increasing risk of a blowout (U.S. Department of the Interior / BOEMRE, 2011).

6. Pumping mud to boat while displacing

   Careful monitoring of displacement volumes in temporary abandonment procedures is critical in order to observe and respond to well kicks (U.S. Department of the Interior / BOEMRE, 2011). Best practices in the deep water drilling industry advise operators to displace drilling mud to a single active pit (storage vessel on the marine unit) in order to facilitate this monitoring (U.S. Department of the Interior / BOEMRE, 2011). In the case of the temporary abandonment of the Macondo well, however, operators displaced drilling mud to multiple pits on the boat, which was not optimal and prevented mudloggers from accurately monitoring the volume of fluid coming out of the well (U.S. Department of the Interior / BOEMRE, 2011).

7. Lost Circulation Material ("LCM") pills combined for Spacer

   Spacer fluid is used in the context of displacement procedures to separate drilling mud from seawater (in displacement, drilling mud is removed and replaced by seawater) (U.S. Department of the Interior / BOEMRE, 2011). In the case of the Deepwater Horizon, operators utilized a large amount of lost circulation material (material used to prevent lost returns of drilling mud into the formation) as a spacer (U.S. Department of the Interior / BOEMRE, 2011). This decision is portrayed in the 2011 report as a sort of improvisation by BP in order to avoid disposal costs for the lost circulation material, indicating that the risk and possible interaction between this improvised spacer material and the well equipment and interfaces with seawater and drilling mud (U.S. Department of the Interior / BOEMRE, 2011).

Fig. 5: Relative location of the hydrocarbon bearing sandstone formations (Pay Sands). (Deepwater Horizon Study Group, 2011)

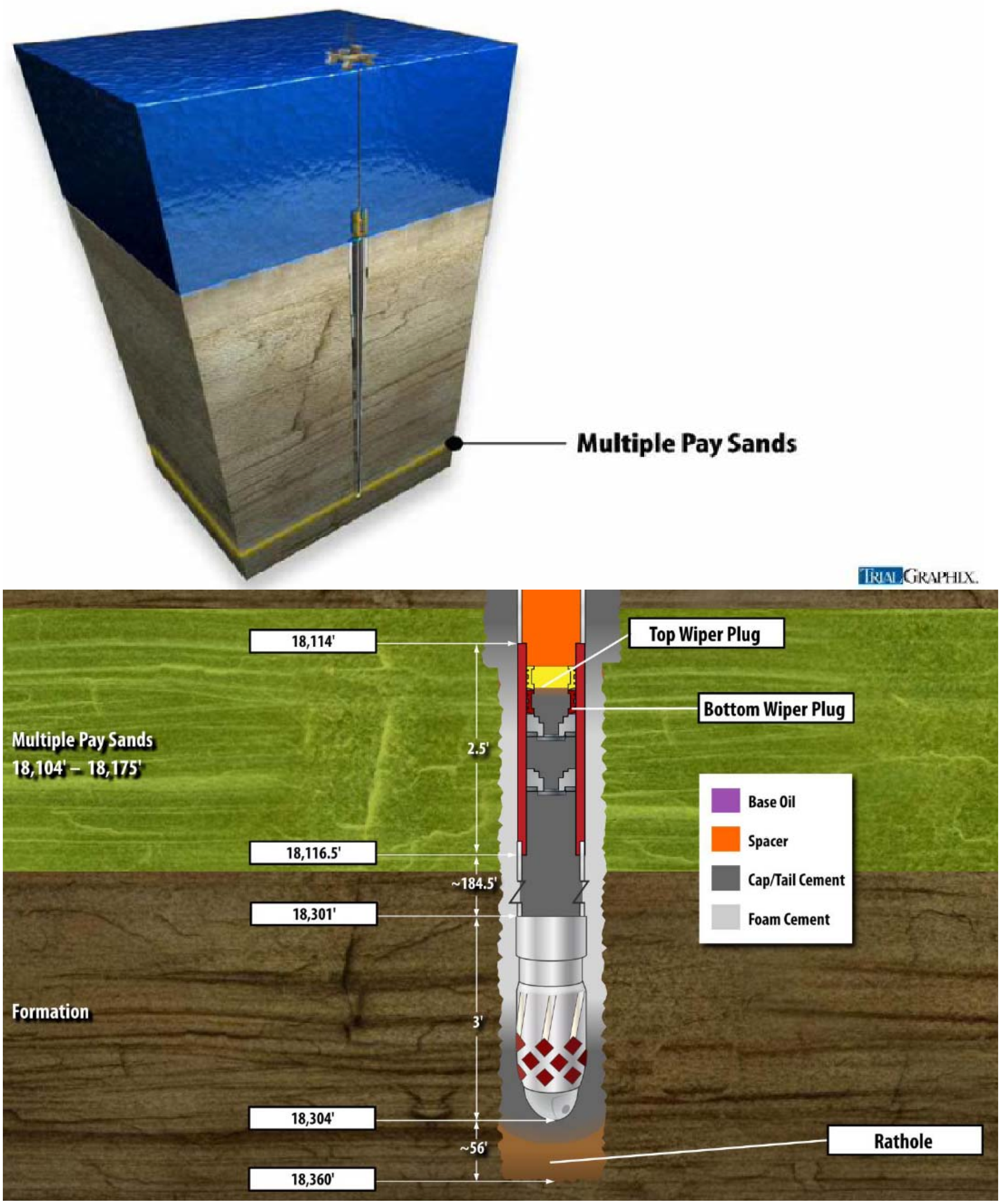
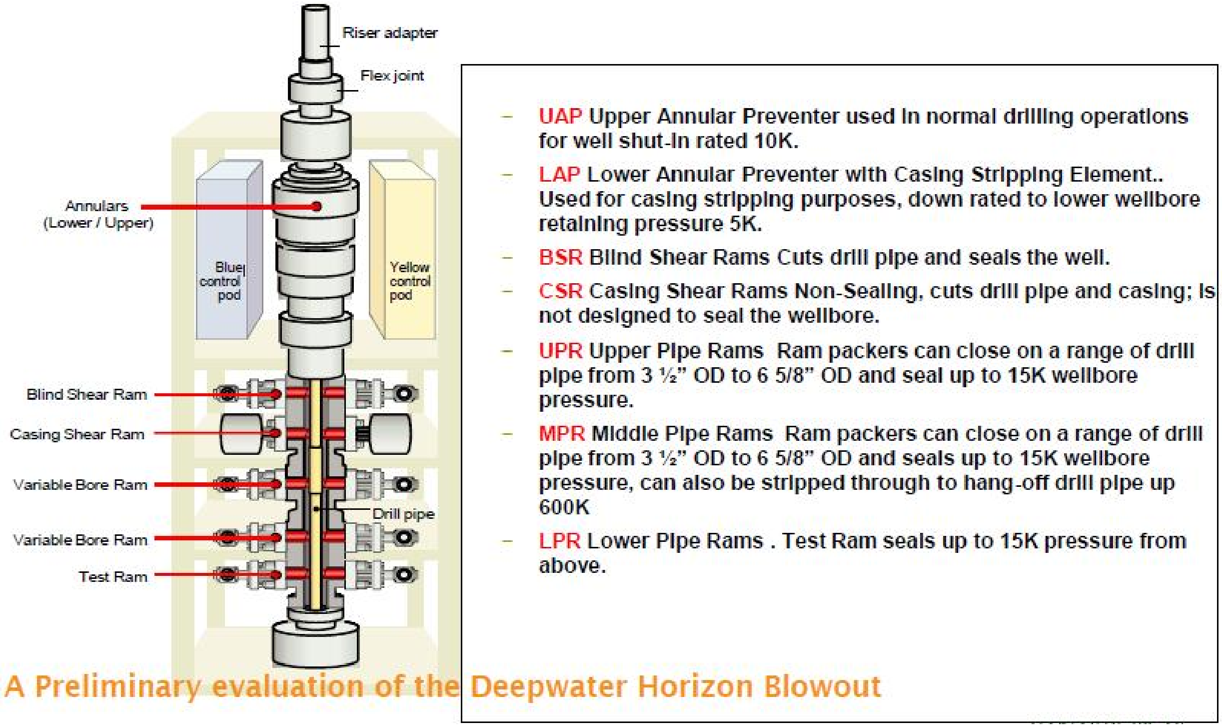


Image Source: Adapted from the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Op. ct. 24.

Fig. 6: The Blowout Preventer used on the Deepwater Horizon (Deepwater Horizon Study Group, 2011)

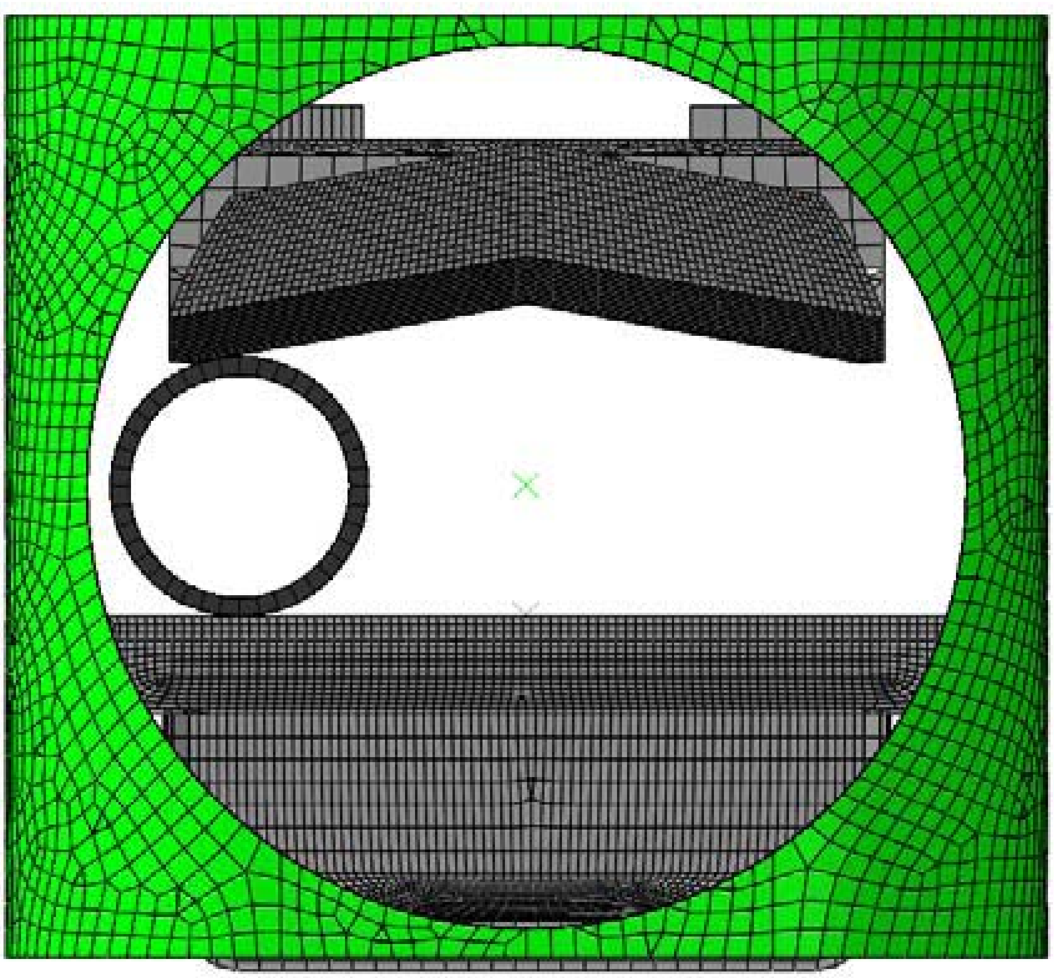


- **UAP** Upper Annular Preventer used in normal drilling operations for well shut-in rated 10K.
- **LAP** Lower Annular Preventer with Casing Stripping Element.. Used for casing stripping purposes, down rated to lower wellbore retaining pressure 5K.
- **BSR** Blind Shear Rams Cuts drill pipe and seals the well.
- **CSR** Casing Shear Rams Non-Sealing, cuts drill pipe and casing; Is not designed to seal the wellbore.
- **UPR** Upper Pipe Rams Ram packers can close on a range of drill pipe from 3 ½" OD to 6 5/8" OD and seal up to 15K wellbore pressure.
- **MPR** Middle Pipe Rams Ram packers can close on a range of drill pipe from 3 ½" OD to 6 5/8" OD and seals up to 15K wellbore pressure, can also be stripped through to hang-off drill pipe up 600K
- **LPR** Lower Pipe Rams . Test Ram seals up to 15K pressure from above.

A Preliminary evaluation of the Deepwater Horizon Blowout

Image Source: Aconawellpro, ref: http://www.aconawellpro.com/@api/deki/files/251/=MiniSeminar_Macondo_August_2010.pdf.

Fig. 7: Off Center Drill Pipe (U.S. Department of the Interior / BOEMRE, 2011).



Source: DNV

VITA

The author was born in New Orleans, Louisiana. She obtained her Bachelor's degree in Fine Arts from the Savannah College of Art and Design in 2010. She entered the University of New Orleans to pursue a Masters Degree in Urban and Regional Planning in 2011 and served as Planning Intern for the Jefferson Parish Planning Department from 2011-2013