A Signal Detection Model to Interpret Safety Tests in Offshore Oil Drilling: A Case Study to Analyze Negative Pressure Test (NPT) Interpretation in Offshore Drilling

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Outline

- Vital Need to Offshore and Deep-water Drilling
- Offshore Drilling as a High-Risk Industry
- Why Risk Analysis Practices?
- Analyzing Human and Organizational Factors
- Concentrating on Negative Pressure Test
- Signal Detection Model Parametric Equations
- A Case Study to Quantify the Signal Detection Model
- Sensitivity Analysis
- Summary and Conclusion
Offshore Drilling: A Vital Source of Oil Supply

Global crude oil production, 2005-15
million barrels per day

(EIA, 2016)
Why Deep-water Drilling Is Noteworthy?

Wells drilled in the Gulf of Mexico by water depth from 1940 to 2010 (Report to the President, 2011, page 41)
Offshore Drilling & Production: High-Risk Industry

Offshore drilling is one of the high-risk industries with “tightly coupled” and “interactively complex” operations.
Case Study: Deepwater Horizon (DWH) Accident

- April 20, 2010
- 11 people died, 17 injured
- 5 million barrels of spilled oil ~ 682,000 tons in 87 days
- Huge environmental damages, influencing small local businesses, and tourism
- Billions of dollars of cost
DWH Was Due to a Series of Technical Failures

- **Well design:**
  - Narrow drilling margin
  - Long string instead of a liner

- **Cementing**
  - Cement material
  - *Number of centralizers*

- **Negative Pressure Test (NPT) misinterpretation**

- **Blowout Preventer (BOP) failure**

- **Mud-gas separator**

- **Alarm systems**
Higher Risk of Deep-water Drilling

- **More** complex casing designs
- **Higher** pressure
- **More** difficult formations
- **Higher** uncertainty of seismology
- **Higher** challenges in accessing the site and wellhead
- **Lower** availability of experienced personnel
Why Risk Analysis Practices?

Trade-off between high risk of deep-water offshore drilling and the rising dependence of oil and gas supply to it

“Government agencies that regulate offshore activity should reorient their regulatory approaches to integrate more sophisticated risk assessment and risk management practices into their oversight of energy developers operating offshore.”

Report to the President, National Commission on the BP DWH Oil Spill, 2011, Page 251
Why NPT?

- The primary way of ascertaining well integrity in offshore drilling
- Manageable scope of work
- NPT misinterpretation was a major contributing cause of the DWH accident

NPT: Negative Pressure Test
Significance of Negative Pressure Test

“If the negative pressure test had been correctly interpreted, the blowout, explosion, fire, and oil spill would have been averted. Consequently, the Court finds that the misinterpretation of the negative pressure test was a substantial cause of the blowout, explosion, fire, and oil spill.”

Findings of fact and conclusions of law phase one trial, Oil Spill by the Oil Rig “Deepwater Horizon” in the GOM, The United States District Court for the Eastern District of Louisiana, September 2014, Page 65
Dissecting “Standard” (Should be Done) Negative Pressure Test
Why Human and Organizational Factors (HOFs)?

Long-term study (1988-2005) of more than 600 well documented major failures in offshore structures: approximately 80% of the major failures were due to **HOFs**.

Chief Counsel’s report (2011) on the DWH: “what the investigation makes clear, above all else, is that **management failures**, not mechanical failings, were the ultimate source of the disaster.”

Lord Cullen in the 25th anniversary of Piper Alpha (2013): “as I dug down to the background of what happened, I discovered it was not just a matter of technical or human failure. As is often the case, such failures are indicators of **underlying weaknesses in management of safety**.”

There is a critical gap in the literature regarding the existence of enough risk assessment approaches analyzing the crucial role of HOFs.
Conceptual Risk Analysis Framework for NPT Misinterpretation

- Organizational Factors
- Decisions/Actions
- Basic Events
Conceptual Risk Analysis Framework for NPT Misinterpretation

Organizational factors level
- Failed to follow MOC processes
  - Oversimplified instructions for the NPT
  - Last minute change to the NPT procedure
  - Last minute change of personnel

Economic pressure
- Production vs. Safety
  - Conflicting priorities in personnel's reward system
  - Time pressure (cost saving)

Personnel Mgmt. issues
- Lack of sufficient training (both in BP and Transocean)
- Insufficient experience

Procedural issues
- No specific, documented procedures for T
c- No interpretation of guidance in the industry regulations or in BP
- No requirement to document the lessons learned

Issues in communication & processing of uncertainties
- BP's failure to communicate the risk of their decisions with Transocean
- Failure to inform the rig crew about the increased risk of well control
- BP's failure to communicate their developed risk assessment system with the onboard leadership
- Failure to communicate the importance of NPT to personnel

Lack of an integrated, informed Mgmt.
- No feedback/processed control from the onshore managers or the executives for the NPT
- Managers' failure to emphasize the particular importance of the NPT
- Lack of real-time operation center to continuously monitor the wellsite operations data

Decisions/Actions level
- Type of spacer to use
- Amount of spacer to use
- Open annular preventer and circulate back mud/spacer above the BOP stack
- Check whether all the mud/spacer above the BOP stack
- Make sure the valve upstream is closed to make 'P20'
- Calculate expected bleed-off volume to make 'P40'
- Simultaneous operation
- Crew's ability to monitor the P1 level
- Further investigation of real-time data by onshore Mgmt.
- Presence of required staff, e.g., drilling engineers, on the rig

Physical states of system/Basic events level
- Viscous material being present across the choke & kill line
- Plugged kill line
- Pressure difference between the drillpipe & kill line
- # of barrels of bleed-off fluid expected
- Pressure built-up after fluid bleed-off
- "P" cannot be bled off to zero

Part of mud/Spacer below the BOP stack
Leak in the annular preventer
Flow from the wall

Negative Pressure Test (NPT) misinterpretation
- Failure to observe and respond to critical indicators
A Snapshot of the Signal Detection Model for NPT Interpretation

**AP Leak:**

Leak in the annular preventer

- AP Leak & Well Leak: Yes/No
- Target variable: Finite continuous
- Decisions/judgments: OK/NOT OK
Two Variables Affecting our Target Variable (Pressure Deviation)

Leak in the BOP annular preventer
(Source of image: Chief Counsel’s Report, 2011, page 154)

Possible flow paths for hydrocarbon
(Source of image: Chief Counsel’s Report, 2011, page 39)
Decision Processes in Signal Detection Theory

Physical World → Sensory Processes → Inference & Decision Processes → Response Behavior

Signal detection theory and decision processes (Green and Swets, 1974; Deplancke and Sparrow, 2014)
Signal Detection Theory

Correct Rejection

Noise

Signal

Hit

Miss

False Alarm

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<th>No</th>
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<td>Correct Rejection</td>
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States of the System

Classification of states: AP Leak, Well Leak

- **Normal state:**
  - $h_0$: NN

- **Abnormal states:**
  - $h_1$: YN
  - $h_2$: NY
  - $h_3$: YY

- $P(h_0) = P(\text{NN})$
- $P(h_1) = P(\text{YN})$
- $P(h_2) = P(\text{NY})$
- $P(h_3) = P(\text{YY})$
Signal Detection Model Notations

Probability of each state for (AP Leak, Well Leak):

\[ P(\text{AP Leak, Well Leak}) = P(\text{AP Leak}) \times P(\text{Well Leak}) \]

e.g.
\[ P(\text{NN}) = P(\text{AP Leak}=N) \times P(\text{Well Leak}=N) \]
Signal Detection Model for NPT Interpretation

Say “H₀“ or OK iff:

- Observe a value for pressure deviation from the system; AP-EP = d
- Is the judgment? OK) or “H₁” (NOT OK)

: Likelihood Ratio

: Conditional probability of the pressure deviation knowing that the state is “h₁”

Cₗj: Cost of saying “H_j” when the state is “hᵢ”

Calculate the cut-off point value “e” for the pressure deviation: Judgment is “H₁” or NOT OK for any observed pressure more than “e”
Signal Detection Model Required Inputs

The cut-off point value depends on three main inputs:

1) $P(h_i)$: Prior probability of the state “$h_i$”; $i=0,1,2,3$
2) $f(x|h_i)$: Conditional probability of pressure deviation for state “$h_i$”
3) $C_{ij}$: Cost of saying “$H_j$” while the state is “$h_i$”; $i=0,1,2,3$ and $j=0,1$
Results of Signal Detection Model Analysis

- Cut-off point value for the above inequality knowing the values for the main three inputs:
  \[ e = 247 \text{psi} \]

- How a pressure deviation as high as “1400psi” was accepted by the DWH crew?

- For any observed pressure built-up more than 247psi: say “\( H_1 \)” or NOT OK
The Cut-off Point Illustration and Meaning
Bias 1: Underestimating Prior Probability of Abnormal States

Cut-off point "e" Vs. P(AP Leak=Y)

Cut-off point "e" Vs. P(Well Leak=Y)
Bias 1: Underestimating Prior Probability of Abnormal States-Cont’d

Cut-off point "e" Vs. P(AP Leak=Y)

Cut-off point "e" Vs. P(Well Leak=Y)
Root Causes of Biases

Organizational factors are the root contributing causes of biases:

- Economic pressure
- Personnel management issues
- Issues in communication and processing of uncertainties
- Lack of an integrated, informed management
Summary and Conclusion

- There is a need for more sophisticated risk analysis methodologies to reduce the high risk of accidents and blowouts in future offshore drilling.
- The developed methodology in this study is an attempt of utilizing sophisticated risk analysis practices, and this methodology can be generalized to other applications as well.
- We proposed a **structured** signal detection model with **parametric equations** for it in order to analyze critical decision making situations and involved biases. This model can be used in different safety-critical systems such as oil and gas industry, healthcare, transportation and financial systems.
- Biases, such as underestimating the prior probability of abnormal states, affect rational decision making and increase the risk of a false negative situation or misinterpreting a negative pressure test.
- Misinterpretation of a conducted NPT can mostly occur due to the confluence of different biases rather than just one specific bias.
- Organizational factors are the root causes of involved decision making biases.
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- Dupriest, F. (2014a) Personal Communication, Retired ExxonMobil chief drilling engineer, Lecturer at Texas A&M University, January 18
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Projection of Deep & Ultra Deep-water Drilling

Libra field; Brazil:

- Off Rio de Janeiro coast
- 7000 meters ~ 23000ft depth
- 8-12 billion barrels of oil

Economist, October 26, 2013
Significance of Negative Pressure Test

The Honorable Dr. Donald Winter in his interview with Platts: BP Deepwater Horizon was precipitated “not by a piece of hardware, but by the decision to proceed to temporary abandonment in spite of the fact that the negative pressure test had not been passed” (November 4, 2013).
Observations from the 3-Layer Conceptual Model

- Organizational factors are root causes of accumulated errors and questionable decisions/actions made by personnel and management.

- The first three organizational factors with the highest influence:
  1. Personnel Management issues
  2. Issues in communication and processing of uncertainties
  3. Economic pressure
Conditional Probabilities and Well Characteristics

- Specifications and range of each conditional probability distribution for the target variable in each state depends on the analyzed well characteristics, such as **depth of drilling**, **depth of displacement**, **formation characteristics**, and **type and amount of used fluids** (e.g. oil based mud vs. water based mud, spacer)

- Considered values for each conditional probability are based on characteristics of a well like the Macondo.

  For example:
  When there is leaking in the annular preventer (state “h₁”), for a case like the DWH, based on the 421bbls of used spacer, in the worst case, the bottom of the spacer can be at 8367ft and the top at about 3000 ft.
Say “$H_0$” or OK iff:

Expected value for saying or judging $H_i$ after observing the value “d” from the system for our target variable
Parametric Decision Making Equations-2

By substituting the equality (2.1) in (1.1):

By simplifying inequality (1.2):

For the expected cost:
Post-Mortem Analysis of the DWH NPT

Under what circumstances could the DWH crew accept the negative pressure test results with a pressure built-up of “1400psi”?  

- **Basic scenario:**
  - \( P(\text{AP Leak}=Y) = 0.01 \)
  - \( P(\text{Well Leak}=Y) = 0.02 \)
  - \( \frac{C_{20}}{C_{01}} \) and \( \frac{C_{30}}{C_{01}} = 2000 \)

  Cut-off point = 247psi

- **Scenario 1:**
  - \( P(\text{AP Leak}=Y) = 0.01 \)
  - \( P(\text{Well Leak}=Y) = 0.00001 \)
  - \( \frac{C_{20}}{C_{01}} \) and \( \frac{C_{30}}{C_{01}} = 300 \)

  Cut-off point = 837psi  \((\text{Which is still less than 1400psi})\)

- If the above cost ratios reduce to 250: the cut-off point will be infinity, which means accepting the test for any observed pressure built-up; no matter how high it is.
Root Causes of Biases

Organizational factors are the root contributing causes of the stated biases:

- **Economic pressure**: if there is too much pressure on cost and time saving, that can cause underestimation of the described cost ratio (cost of accepting the test for an abnormal state to the cost of rejecting the test for a normal state).

- **Personnel management issues**: if personnel does not receive proper training or does not have enough experience, that can cause the described biases.

- **Issues in communication and processing of uncertainties**: if managers do not communicate the risk of complex operations such as NPT procedures to personnel, that can contribute to the described biases.

- **Lack of integrated, Informed management**: existence of no integrated feedback system from managers (both onshore and offshore) to the crew can contribute to the described biases.