Analysis and Discussion of Deepwater Horizon Accident and Barrier Strategies

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Introduction

Summary of Macando Blowout
Comparison to other similar accidents

Failed Barrier Analysis

Step Diagram
MTO Analysis
Bow-Tie Diagram

Proposed Barrier Strategy

PSA Process
Hazard Identification
Specific Barrier Strategy
Barrier Requirements

Conclusion
# Accident Summary

<table>
<thead>
<tr>
<th></th>
<th>Nov-09</th>
<th>Dec-09</th>
<th>Jan-10</th>
<th>Feb-10</th>
<th>Mar-10</th>
<th>Apr-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
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<td>1 2</td>
<td>3</td>
<td>1 2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Mon</td>
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<td>5</td>
<td>3 4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>Tue</td>
<td>5 6</td>
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<td>7</td>
<td>5 6</td>
<td>7</td>
<td>8</td>
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<td>Wed</td>
<td>6 7</td>
<td>6 7</td>
<td>8</td>
<td>6 7</td>
<td>8</td>
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<tr>
<td>Thu</td>
<td>7 8</td>
<td>7 8</td>
<td>9</td>
<td>7 8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Fri</td>
<td>8 9</td>
<td>8 9</td>
<td>10</td>
<td>8 9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Sat</td>
<td>9 10</td>
<td>9 10</td>
<td>11</td>
<td>9 10</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

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## Similar Blowout Accidents

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
<th>Initiating Event</th>
<th>Accident Progression</th>
<th>Fatalities</th>
<th>Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macondo 2010</td>
<td>March 2010</td>
<td>High pressures in the wellbore</td>
<td>Well abandonment- kick in well- hydrocarbon leak- two explosions</td>
<td>11 of 126 (9%)</td>
<td>126 people</td>
</tr>
<tr>
<td>Usumacinta 2007</td>
<td>April 2007</td>
<td>Bad weather</td>
<td>Storm- hydrocarbon leak</td>
<td>22 of 81 (27%)</td>
<td>81 people</td>
</tr>
<tr>
<td>Enchova 1984</td>
<td>June 1984</td>
<td>Unknown</td>
<td>Drilling- Gas leak</td>
<td>42 of 249 (17%)</td>
<td>249 people</td>
</tr>
</tbody>
</table>

The evacuation process in Deepwater Horizon, did not result in fatalities [Vinnem, 2014].

One could infer that Transocean had better evacuation procedures than PEMEX (Usumacinta) or Petrobras (Enchova).
Introduction
Failed Barrier Analysis
Proposed Barrier Strategy
Conclusion

Step Diagram

Actors

Halliburton

BP

Transocean

Minerals Management Services

Events

February 2010
March 2010
April 2010
April 19 2010
April 21 2010
April 22 2010
April 23 2010
April 24 2010
April 25 2010
April 26 2010
April 27 2010
April 28 2010
April 29 2010
April 30 2010
May 1 2010
May 2 2010
May 3 2010
May 4 2010
May 5 2010
May 6 2010
May 7 2010
May 8 2010
May 9 2010
May 10 2010
May 11 2010
May 12 2010
May 13 2010
May 14 2010
May 15 2010
May 16 2010
May 17 2010
May 18 2010
May 19 2010
May 20 2010
May 21 2010
May 22 2010
May 23 2010
May 24 2010
May 25 2010
May 26 2010
May 27 2010
May 28 2010
May 29 2010
May 30 2010
May 31 2010

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**Failed MTO Barriers**

Failures in the intersection of man and organizational barriers are higher in number than other categories.

The combination of man and organization resulted in six failed barriers.
Introduction
Failed Barrier Analysis
Proposed Barrier Strategy
Conclusion

Step Diagram
MTO Analysis
Bow-Tie Diagram

Bow-Tie Diagram

Barrier Legend
- Man
- Technology
- Organization

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PSA Barrier Management Process

Figure: [PSA, 2013]
## Hazard Identification

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Generic Hazard</th>
<th>Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>High/unstable pressure in the well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degradation of equipment</td>
</tr>
<tr>
<td>2</td>
<td>Dangerous materials</td>
<td>Flammable</td>
</tr>
<tr>
<td>3</td>
<td>Thermal hazards</td>
<td>Flame</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Explosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Personnel exposed to high temperature and heat radiation</td>
</tr>
<tr>
<td>4</td>
<td>Organizational hazards</td>
<td>Safety culture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less than adequate maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less than adequate competence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crowd control</td>
</tr>
</tbody>
</table>

[Rausand, 2011]
## Terminologies

<table>
<thead>
<tr>
<th>Generic Hazard</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical, dangerous, thermal and organizational.</td>
<td>Evaluating likelihood of occurrence of an accident event.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify and arrange different probable causes.</td>
<td>Evaluating consequences if an accident event occurs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Initial Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific hazard in relation to generic hazard.</td>
<td>Factor of probability, severity and lack of preventive measures.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accidental Event</th>
<th>Residual Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe what, when, where things can go wrong.</td>
<td>Factor of probability, severity and introduction of preventive measures.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Probable Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Causes triggering the accidental event.</td>
</tr>
</tbody>
</table>
### Risk Picture

#### Initial Risk Picture

<table>
<thead>
<tr>
<th>Frequency/Consequence</th>
<th>1-Very Unlikely</th>
<th>2-Remote</th>
<th>3-Occasional</th>
<th>4-Probable</th>
<th>5-Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Catastrophic</td>
<td></td>
<td></td>
<td>3b, 5e, 5g</td>
<td>1a, 2a, 3a, 5b</td>
<td></td>
</tr>
<tr>
<td>3-Critical</td>
<td></td>
<td>1d</td>
<td>1b, 5f</td>
<td>1c, 5d</td>
<td>4b, 4c, 4e, 5a</td>
</tr>
<tr>
<td>2-Major</td>
<td></td>
<td></td>
<td></td>
<td>3c, 5c</td>
<td>4a, 4d</td>
</tr>
<tr>
<td>1-Minor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Residual Risk Picture

<table>
<thead>
<tr>
<th>Frequency/Consequence</th>
<th>1-Very Unlikely</th>
<th>2-Remote</th>
<th>3-Occasional</th>
<th>4-Probable</th>
<th>5-Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Catastrophic</td>
<td></td>
<td></td>
<td>1d, 2a, 3a, 3b, 5b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Critical</td>
<td></td>
<td></td>
<td>1b, 5d, 5g</td>
<td>1a, 3c, 4a, 4c, 4d, 4e, 5a, 5e, 5f</td>
<td>1c</td>
</tr>
<tr>
<td>2-Major</td>
<td></td>
<td></td>
<td></td>
<td>1b, 5d, 5g</td>
<td>1c</td>
</tr>
<tr>
<td>1-Minor</td>
<td></td>
<td></td>
<td></td>
<td>5c</td>
<td>4b</td>
</tr>
</tbody>
</table>
**Barriers according to PSA Memo- Part 1**

**Reduce Risk of Hydrocarbon Leak from the Well**

- Isolate areas with different pressures and fluids.
- Prevent collapsing and leak of well formation.
- Regulate flow of Hydrocarbons
- Isolated hydrocarbons subsea.
- Avoid Rig Drift and Drive off
- Kill the well
- Avoid External Ship Collision

**Barrier Functions**
- Risers
- BOP
- Casing
- Casing
- Centralizers
- Drilling Mud
- BOP
- Choke Valve
- Emergency Shutdown
- Kill Line Valve

**Sub-Functions**
- Pressure Testing (Negative and Positive)
- Bottoms-up
- Dynamic Positioning System
- Collision Avoidance Alarms
- Safety Zone Regulations

**Barrier Elements**
- Drilling Mud
- BOP
- BOP
- Emergency Shutdown
- Kill Line Valve

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**Organization and Man barriers are included in each barrier element because the selection of the above physical barriers depends on the individual/organization perceptions in form of analysis and design.**

- Management focus on safety through campaigns. (Top to bottom and bottom to top)
- Accountability of the company towards safety incidents through industry and national regulations
- Establishing single point of contacts and analysing it through Social Network Analysis tools
- Continuous improvement of safety drive in the company and expansion of each project’s Risk Analysis Assessment to keep up with changes made to the original plan during the execution phase – continuous reassessment of the risk picture.
- Periodically re-optimize maintenance costs
- Investment in continuous training of personnel in best available safety practices
- Investment in mentoring programmes
- Hiring competent personnel
- Sharing lessons learnt to other companies
- Timely certification and maintenance of safety critical systems

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### PSA Process

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Performance Standard (Functionality, Integrity, Vulnerability)</th>
<th>Performance Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolate areas with different pressures and fluids</td>
<td>Functionality</td>
<td>Established pressure limits in various zones</td>
</tr>
<tr>
<td>Prevent collapsing and leak of well formation</td>
<td>Functionality</td>
<td>Loss of drilling mud should not exceed the given limit</td>
</tr>
<tr>
<td>Regulate flow of Hydrocarbons</td>
<td>Integrity</td>
<td>Minimum failure rate of BOP through quantitative analysis. Example- SIL analysis</td>
</tr>
<tr>
<td>Isolated hydrocarbons subsea</td>
<td>Integrity</td>
<td>Minimum failure rate of BOP through quantitative analysis. Example- SIL analysis</td>
</tr>
<tr>
<td>Avoid Rig Drift and Drive off</td>
<td>Functionality</td>
<td>Limits and accuracy dynamic positioning system envelopes</td>
</tr>
</tbody>
</table>
## Barrier Performance Requirement - Element Level

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Performance Standard (Functionality, Integrity, Vulnerability)</th>
<th>Performance Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire and Gas Detectors</td>
<td>Integrity</td>
<td>Determine acceptable failure rate of detectors through quantitative analysis. Example- SIL analysis</td>
</tr>
<tr>
<td>Emergency Safety Procedures Safety Alarms</td>
<td>Functionality, Integrity</td>
<td>Be aligned with the risk picture</td>
</tr>
<tr>
<td>Sprinklers</td>
<td>Integrity</td>
<td>Determine acceptable failure rate of detectors through quantitative analysis. Example- SIL analysis</td>
</tr>
<tr>
<td>Process Shutdown Systems</td>
<td>Integrity</td>
<td>Determine acceptable failure rate of FF equipment through quantitative analysis. Example- SIL analysis</td>
</tr>
<tr>
<td>Lifeboats</td>
<td>Functionality</td>
<td>Have sufficient capacity to include all personnel on-board the rig</td>
</tr>
<tr>
<td>Support Vessels</td>
<td>Functionality</td>
<td>Response to an emergency call within a given time limit</td>
</tr>
<tr>
<td>Restricted Personnel Access Areas</td>
<td>Functionality</td>
<td>Normally manned working stations should be sheltered or out of reach from potential explosions caused by HC release</td>
</tr>
<tr>
<td>Personnel Protective Equipment</td>
<td>Vulnerability</td>
<td>Guarantees impact and thermal protection to a stipulated level</td>
</tr>
</tbody>
</table>
### Barrier Performance Requirement - Organizational Level

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Performance Standard (Functionality, Integrity, Vulnerability)</th>
<th>Performance Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management focus on safety through campaigns</td>
<td>Functionality</td>
<td>Commit management time to safety activities. Safety walk. Walk-Observe-Feedback. Social corporate responsibility drive</td>
</tr>
<tr>
<td>Accountability of the company towards safety incidents through industry and national regulations</td>
<td>Functionality</td>
<td>Make contact information of single points of contact public and know</td>
</tr>
<tr>
<td>Establishing single point of contacts and analyzing it through Social Network Analysis tools</td>
<td>Functionality</td>
<td>Risk Analysis Assessments should be reviewed at fixed intervals during planning phase and whenever a major modification to plan occurs during project execution</td>
</tr>
<tr>
<td>Continuous improvement of safety drive in the company and expansion of each projects Risk Analysis Assessment to keep up with changes made to the original plan during the execution phase - continuous reassessment of the risk picture. Periodically re-optimize maintenance costs</td>
<td>Functionality</td>
<td>At predetermined given time intervals, aiming to cut a given percentage of labor</td>
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</table>
## Barrier Performance Requirement- Organizational Level

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Performance Standard (Functionality, Integrity, Vulnerability)</th>
<th>Performance Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment in continuous training of personnel in best available safety practices</td>
<td>Functionality</td>
<td>Annual evaluation of relevant technical knowledge</td>
</tr>
<tr>
<td>Investment in mentoring programmes</td>
<td>Functionality</td>
<td>Ensure mentoring program for new employees</td>
</tr>
<tr>
<td>Hiring competent personnel</td>
<td>Functionality</td>
<td>Assessment of technical knowledge and personality</td>
</tr>
<tr>
<td>Sharing lessons learnt to other companies</td>
<td>Functionality</td>
<td>Target number of published industry white papers</td>
</tr>
<tr>
<td>Timely certification and maintenance of safety critical systems</td>
<td>Integrity</td>
<td>Traceability of equipment and process certificates</td>
</tr>
</tbody>
</table>
Conclusion

1. Complex systems = complex accident propagation

2. Risk analysis must be performed and updated

3. Barrier management is paramount

4. Organizational and human barriers are constantly in demand during accident progression

5. Systems safety should not be neglected in favor of traditional HSE indicators
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