Leading Safety, Health, and Environmental Indicators in Oil and Gas Industry (with the Focus on Hydraulic Fracturing)

Nima Jabbari, Ph.D., P.E.
Introduction

- **Incidents**: financial and environmental damages, harm the reputation and sully the image of the industry

- Nov. 4 (2014) Referendum in *Denton, TX*: banned fracturing

Need to alleviate public’s concern and get their CONFIDENCE
Introduction

• Proactive system-oriented approach: helps in sustainable shale industry

• Efforts put on prevention translates into:
  o Safer industry - Social acceptance - Higher production

Need to Learn From Other Industries!

Leading Indicators: key in assuring safer operations
Leading and Lagging Indicators

• **Lagging Indicators**: facts about previous events, after an incident occurs (e.g. injury rates)

• **Leading Indicators**: pre-incident measurements, have a predictive quality (e.g. monitoring gas level)

• Application of indicators in upstream and downstream industries:
  - **NAE/NRC (2011)**: the BP Deepwater Horizon accident
  - **CBS (2007)**: BP Texas City Refinery incident
  - **CBS (2014)**: Tesoro Anacortes Refinery incident
  - **CBS (2015)**: Chevron Richmond Refinery

• Types and Characteristics
### Leading Indicators Characteristics

<table>
<thead>
<tr>
<th>Organization</th>
<th>Characteristics of Leading Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>API</strong></td>
<td>• Reliable</td>
</tr>
<tr>
<td></td>
<td>• Repeatable</td>
</tr>
<tr>
<td></td>
<td>• Consistent</td>
</tr>
<tr>
<td><strong>NSC</strong></td>
<td>• Actionable</td>
</tr>
<tr>
<td></td>
<td>• Meaningful</td>
</tr>
<tr>
<td></td>
<td>• Transparent</td>
</tr>
<tr>
<td><strong>IAEA</strong></td>
<td>• Direct relationship between the indicator and safety</td>
</tr>
<tr>
<td></td>
<td>• Availability of required data</td>
</tr>
<tr>
<td></td>
<td>• Unambiguous</td>
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</table>
## Leading Indicators Types

<table>
<thead>
<tr>
<th>Organization</th>
<th>Types of Leading Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>API</td>
<td>• Process Hazard Evaluations Completion</td>
</tr>
<tr>
<td></td>
<td>• Training Completed on Schedule</td>
</tr>
<tr>
<td></td>
<td>• Procedures Current and Accurate</td>
</tr>
<tr>
<td></td>
<td>• Safety Critical Equipment Inspection</td>
</tr>
<tr>
<td></td>
<td>• Completion of Emergency Response Drills</td>
</tr>
<tr>
<td></td>
<td>• Fatigue Risk Management</td>
</tr>
<tr>
<td>A major oil company</td>
<td>• PHA [Process Hazard Analysis] Recommendation Implementation Overdue</td>
</tr>
<tr>
<td></td>
<td>• Safety Instrumented Systems (SIS) Functions Disabled</td>
</tr>
<tr>
<td></td>
<td>• SIS [Safety Instrumented System] Functional Test Overdue</td>
</tr>
<tr>
<td></td>
<td>• Investigations</td>
</tr>
<tr>
<td></td>
<td>• Critical Process Variable Deviations</td>
</tr>
<tr>
<td></td>
<td>• Open Temporary Leak Repairs</td>
</tr>
<tr>
<td></td>
<td>• Utilization (Mechanical Utilization)</td>
</tr>
<tr>
<td></td>
<td>• Overdue training</td>
</tr>
</tbody>
</table>
### Ratio of Gas Well Numbers for Different Resources

#### Number of Fractured Wells

<table>
<thead>
<tr>
<th>Resource</th>
<th>Total Wells</th>
<th>Vertical</th>
<th>Horizontal</th>
<th>Total Fractured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>536</td>
<td>315</td>
<td>57</td>
<td>370</td>
</tr>
<tr>
<td>CBM</td>
<td>33</td>
<td>27</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Tight</td>
<td>2,528</td>
<td>2,054</td>
<td>368</td>
<td>2,427</td>
</tr>
<tr>
<td>Shale</td>
<td>2,210</td>
<td>317</td>
<td>1,863</td>
<td>2,188</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5,307</strong></td>
<td><strong>2,713</strong></td>
<td><strong>2,291</strong></td>
<td><strong>5,015</strong></td>
</tr>
</tbody>
</table>

(Shirez et al. 2012)
## Top 10 HSE violations (Marcellus Shale - PA)

<table>
<thead>
<tr>
<th>#</th>
<th>Violation Description</th>
<th>Violation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Failure to properly store, transport, process or dispose of a residual waste.</td>
<td>Environmental Health and Safety</td>
</tr>
<tr>
<td>2</td>
<td>O&amp;G Act 223-General. Used only when a specific O&amp;G Act code cannot be used</td>
<td>Administrative</td>
</tr>
<tr>
<td>3</td>
<td>Failure to minimize accelerated erosion, implement E&amp;S plan, maintain E&amp;S controls. Failure to stabilize site until total site restoration</td>
<td>Environmental Health and Safety</td>
</tr>
<tr>
<td>4</td>
<td>Failure to adopt pollution prevention measures required or prescribed by DEP by handling materials that create a danger of pollution.</td>
<td>Environmental Health and Safety</td>
</tr>
</tbody>
</table>

(Stateimpact 2015)

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Leading Indicators: Upstream vs. Downstream

- API Recommended Practice 754: devised for petrochemical and refinery industry

- No such a thing for upstream production

- Customized guidelines must be developed for each field

- Leading indicators can yet be recognized for hydraulic fracturing industry
Leading Indicators in Hydraulic Fracturing

**Leading Safety Indicators**
- Inherently safe design
- Testing and inspection of the equipments
- Technical competence assessment and assurance
- Assessment of the risk of major incidents
- Quality of and adherence to operating procedures
- Blowout precursor (e.g., loss circulation)
- Mechanical integrity
- Capability of the contractor
- Training and development and workers management
- Asset integrity and process safety initiatives
- Fatigue risk management
- Safety culture

**Pre-Frac**
- Hydraulic Fracturing Data Collection and Design
- Equipment, Water, and Chemicals Transportation
- Drilling, Casing, and Cementing

**Frac**
- Pad Injection
- Proppant Injection

**Post-Frac**
- Returning Waste
- Temporary Storage and Disposal of Waste

**Leading Health and Environmental Indicators**
- Gaseous emissions (e.g., Methane, H₂S, VOCs, CO)
- Aqueous discharges and quality of the wastewater produced
- Non-aqueous hydraulic fracturing and drilling fluids
- Spills of Chemicals and hydrocarbon (MSDS centric precautions and health and environmental indicators)
- Silica exposure
- On-site monitoring (water and air samples)

*MSDS: Material Safety Datasheet

Note: Safety indicators are adapted from different agencies (Listed on table 2). Environmental and health indicators are adapted from (IOGP 2014).
How to make things better?

- A person may not handle 15-16 things at the same time
- Importance of getting automated and sophisticated: sensors and real-time monitoring
- More research to find the holes

James Reason Swiss Cheese Model

Hydraulic Fracturing Incidents: Case-1

- Caddo Parish, LA (2010)
- Striking an unknown gas pocket during initial drilling
- Gas spewed in the air/ infiltrate groundwater
  - 400 residents evacuated
  - Unusable water: not safe to drink, or bathe
- Leading indicators:
gaseous emissions and blowout precursors

Lustgarten (2010)
Hydraulic Fracturing Incidents: Case-2

- Dunn County, ND (2010)
- Uncontrolled blowout in the **fifth stage** of a 23 stage hydraulic fracturing operation
- 84,000 gallons of hydraulic fracturing fluid and oil to the surrounding environment
- Reason: Equipment failure
- Leading Indicators:
  Mechanical integrity tests prior and during the operation

Donovan (2013)
Hydraulic Fracturing Incidents: Case-3

- Clearfield County, PA (2010): Well blowout (returned fluid & drilling waste)
- Malfunction of a blowout preventer
- Operator failed to contain contaminants within the wellbore for 18 hours
  - Gas, drilling waste, and 35,000 gallons of flow-back fluids in a tributary that feeds into a high quality cold water fishery
- Lack of accurate inspection/ Absence of properly trained employees

Malone (2010)
Hydraulic Fracturing Incidents: Case-4

- Billings County, ND (2013): Well blowout

- Compromised plugged packer during the casing stage, resulting in the release of subsurface pressure

- 100 barrels of oil and 4,025 barrels of brine (173,250 gallons of pollutants) were released in 2 days

Sontag and Gebeloff (2014)
Hydraulic Fracturing Incidents: Case-4

- The blowout cause was “an irresponsible supervisor’s callous disregard of” its “well-established standard operating procedures”.
  - human factors

- Human factors could have been mitigated by the proper use of model simulations, equipment training, and safety meetings.
Proposed Steps for Incident Classification

1. Occurrence of an incident
   - Directly caused by underground injection? (Yes/No)
     - Yes: Investigate root-causes
     - No: Preventable during the fracturing phase? (Yes/No)
       - Yes: Investigate root-causes
       - No: Preventable during the pre or post fracturing phases? (Yes/No)
         - Yes: Investigate root-causes
         - No: Incident is caused by non-hydraulic fracturing activities (e.g. natural disaster, Sabotage, etc.)
New Ideas

• Extensive data collection

• Application of data analysis new techniques and soft computing methods (i.e. Machine Learning)

• Goals:

  ✓ To help develop leading indicators to classify incidents

  ✓ To flag situations with higher risk
Construction Industry Example


- Construction: One of the most dangerous industries for workers

- Data used: Safety inspection records, accident cases, and project-related data

- the ML-predicted leading indicator: “No Accident”, “Minor Accident” and “Major Accident” (low, medium and high risk of accidents)
Construction Industry Example – Research Design

- Problem identification
- Data understanding
- Data pre-processing
- Modeling
- Evaluation

Sub-Proceses:
- (Boruta feature selection, DT modeling)
- (SMOTE class-balancing Model tuning, Parameter Optimisation)
- (Performance Metrics: Recall, Accuracy, Weighted-Kappa Statistics)

Output:
- Research Aims & Objectives
- Data description, Appropriate datasets, X-attributes/Y-attributes
- Machine Learning Models: DT, RF, LR, KNN, SVM
- Leading Indicators, Results, Discussion
Concluding Remarks

• Time to wake up to take the people’s confidence

• Learning from other industries is a must: Leading and lagging indicators

• Vital to know the potential safety and environmental hazards for each operation (Flowchart) / Rigid guidelines may not work

• The best way to answer public’s concerns: ensuring the safety of the operations: Automation! People make mistakes

• Pumping money into research development!

• Monitoring and data collection: great tools in developing indicators
Thank you for your attention! Questions?