Intelligent Oilfield Operations
Objective of this presentation

To review current petroleum production issues regarding real time decision making and,

To present the vision of a intelligent oilfield operations

To Promote the use of technologies for intelligent oilfield operations

To present the results of a continuous self-learning optimization strategy to optimize field-wide productivity
Contents

1. The Reservoir Management Challenges
2. Management and Decision Making processes
3. Operators Vision & Strategies
   • Integration of measurement-models-control
   • Rapid front end project planning
   • Collaborative knowledge and application sharing
   • Rapid technology adaptation
4. What are the opportunities for Intelligent Oilfield Operations?
5. Why don’t we use more Intelligent Oilfield Operations?
6. Case Study
Real Time Asset Management Challenge for Adaptation

Drilling and Construction
- Investment Plan
- Fleet Availability
- Workover Candidates

Field Development Planning
- Current Performance
- Field Target Rate
- Valid Models
- Prospects

Production Operations
- Forecast Performance
- Current Performance
- New Data

Integrated Reservoir Modeling
- Prospects
- Current Model

Market

Market

- Producing Wells
- Valid Models
- Current Performance
Reservoir Management is about a careful orchestration of technology, people & resources

The Reservoir Management Challenge

**Exploitation Plan**
- Well location & number
- Recovery mechanism
- Surface facilities
- Well intervention

**Drill, build & Operate**

**Monitor**

**Control**

**Establish or revise Optimum Plan**

Subsurface Characterization

Update Model

Exploitation Plan

- Well location & number
- Recovery mechanism
- Surface facilities
- Well intervention

Drainage Area

Production Well & Facilities

Injection Facilities

Compression & Treatment Plants

**Drill, build & Operate**

**Monitor**

**Control**

**Establish or revise Optimum Plan**

Subsurface Characterization

Update Model
Real-time has different meanings at different levels

**Slower cycle**

- **Business Headquarters**
  - Asset life cycle and installed based maintenance or growth
  - Supply Chain Management & Market and customer demands

- **Capacity Planning Design** [months/years]
  - Planning of injection/production plan and resources
  - Planning drilling and workover resources
  - Supply Chain Management & Market and customer demands

- **Operational Planning** [months/years]
  - Scheduling of injection/production plan and resources
  - Opening and closing wells or partial completions
  - Adjusting well operating parameters

- **Scheduling** [days/months]
  - SCADA systems for coordinating flow stations and pipelines
  - Gas distribution/optimization on a pipeline network
  - Monitoring wellheads, multiples and flow stations

- **Supervisory Control** [minutes/hours]
  - Flow, pressure and temperature in wells and separator
  - Fuel injection to produce heat out of a boiler

- **Regulatory Control** [sec/minutes]

**Fast cycle**

- **Well & Surface facilities**

SPE Paper 77703
Volumetric Success
750 Worldwide Samples

\[ \text{Volumetric Success} = \left( \frac{q_{\text{plan}} - q_{\text{actual}}}{q_{\text{plan}}} \right) \times 100 \]

- Only 15% of the wells lied in ±12.5% range
- 33% of the wells lied in ±25% range
- 48% had success < -25%
- Mean –29%, st.dev. 64%
Volumetric Success Deviation

- Reservoir Uncertainty: 57%
- Operational Drilling Disfunction: 43%

Other contributing factors:
- Inadequate Completion: 33%
- Stimulation Rock & Fluid Characterization: 12% (2 occurrences)
- Sanding Formation Damage Fracturing: 9% (2 occurrences)
- Circulation Losses: 7% (3 occurrences)
- Well Instability: 5%

PDVSA, 1999
**Hydrocarbon production system suffering major technical problems**

## Motivation

<table>
<thead>
<tr>
<th><strong>Traditional Problems</strong></th>
<th><strong>Current Approach</strong></th>
<th><strong>Challenges</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex &amp; risky operations (Drilling, Workover, Prod.)</td>
<td>More front-end engineering and knowledge sharing</td>
<td>More data for analysis and integration limitations.</td>
</tr>
<tr>
<td>Poor reservoir prediction &amp; production forecasting</td>
<td>Integrated Characterization &amp; Modern visualization tools</td>
<td>Long-term studies, Ill-posed tools, simple or incomplete.</td>
</tr>
<tr>
<td>Limited resources: injection volumes, facilities, people.</td>
<td>Multivariable optimization, reengineering.</td>
<td>Models are not linked among different layers</td>
</tr>
<tr>
<td>Unpredictability of events: gas or water, well damage.</td>
<td>Monitoring &amp; control devices, Beyond well measurements</td>
<td>Poor Justification, real time analysis in early stage.</td>
</tr>
<tr>
<td>Poor decision making ability to tune systems, thus, not</td>
<td>Isolated optimization trials with limited success.</td>
<td>Decisions made only on few pieces. Lack of Integration</td>
</tr>
<tr>
<td>optimized operations</td>
<td></td>
<td>between subsurface-surface</td>
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</table>
Intelligent Oilfield Operations’ Vision

To efficiently use of data and information
to generate opportune decisions
in regards to optimum exploitation

- Awareness of Asset Performance
- Transform key data into knowledge
- Shared across relevant people
- Shared across different locations

- How much to inject or produce?
- Where to place new wells?
- How to troubleshoot problems?
- What-if exploitation scenarios?

- Maximum profitability
- Safe and healthy operations
- Asset Integrity
- Environmentally friendly
Intelligent Oilfield Operations’ Elements

Intelligent operations requires

• Seamless integration of field hardware with office decision systems for continuous decision-making in a closed-loop fashion
  – Permanent sensors and remote activated actuators,
  – Surface facilities
  – Integrate subsurface and reservoir models

• Rapid front-end project planning for reduced execution uncertainty;

• Collaborative knowledge and application sharing across multiple disciplines and geographies; and

• Rapid adaptation to technology and to market changes.
Intelligent Oilfield Operation’s Vision

**Optimum Exploitation Plan**
- Self-Learning Reservoir Management

**Automated Fluid Extraction**
Acquisition, Modeling and Control with AI

**Decision Assertiveness**
- Best Practices → KC’s
- High Volumetric and Mechanical Efficiency
- Less Adapting Time
- Project Front-End Loading

**Minimum Cost**

**The Networked Force**
- Large Bandwidth Information
- Integration Engineer

**Business Exploitation Unit**

**Command Control Center and Communications**
- Monitoring 4D
- Up/Downstream Integration
- Real Time Operations Centers

PDVSA, 1996
Intelligent Oilfield Operation Strategies

Integrate Cooperative Technologies (data, apps y processes)
- Multidisciplinary Reservoir Characterization
- Data and Application Integration for decision making
- Subsurface-surface integration
- High Performance Computing – System Architecture
- Closed-Loop Reservoir Management

Increment Well Volumetric and Mechanical Efficiency
- Geologically Optimized Well Placements
- Drilling and Completions Operations Centers
- Enhanced Well Productivity
- Optimize and Relax Surface Constraints

Simplify operations
- Permanent Instrumentation
- Remote Actuation
- Complex Data Mining
- Intelligent agents

Develop & Maintain competencies
- Integration Engineer
- Self Learning
- Multiple vendors talking
- Best Practices

PDVSA, 1996
Permanent Sensors and Remote Actuated Controls?

- Remote Terminal Unit
- Subsea Safety Valve
- Production tubing
- Internal Control Valve
- Resistivity Sensor
- Zone 3 Perforations
- Liner Hanger
- Zone 1 Perforations
- Zone 2 Perforations
- Pressure Sensor
- Temperature Sensor
- Venturi Flow Meter
- Acoustic Sensor

Graphs showing pressure and temperature over time.
Integrate Subsurface and Surface Automation

After SPE Paper 77643 & OTC Paper 16162
What is Rapid and Smart Front-End-Planning?

- Involve all stakeholder at early stages
- Identify and mitigate risk by early planning
  - Reservoir Uncertainty
  - Exploitation Options
  - Project Execution Time
  - Economic Sensitivities
- Identify, preserve and apply best practices
- Integrate computer aided high intensity design and design optimization techniques
Knowing input-output relationships, reservoir could be seen as a process plant

Reservoir as a Process Control System Structure

Manipulated Inputs
- Flow Choke
- Zone Control
- ESP Speed
- Gas Lift
- Solvent Injection
- Water Injection
- Heat Injection
- Gas Injection

Measured Disturbances
- Backpressure
- Ambient Temperature
- Flow Restrictions
- Injection Fluid Restriction

Unmeasured Disturbances
- Reservoir Rock Heterogeneity
- Reservoir Fluid Distribution
- Scheduling

Feed forward path

Manipulated Inputs
- Controller

Measured Outputs
- Well flowing Pressure: \( p_{wrf} \)
- Reservoir Pressure: \( p_{res} \)
- Reservoir Saturations: \( S_o, S_w \)
- Flow Impairment: \( S, K_r's \)
- Zone Multiphase Flow: \( q_o, q_w, g_q \)
- Drainage Area: \( A \)

Unmeasured Outputs
- Tubing Head Pressure: \( p_{THP} \)
- Tubing Head Temperature: \( T_{THT} \)
- Multiphase Flow: \( q_o, q_w, g_q \)
- Solid Production, Water Analysis
Oil, water and gas flow and pressure as linear functions of flowing pressure

Reservoir Flow and Pressure Modeling

Proposed IPR for continuous monitoring

\[ q_o^k = a_0 + a_1 \times p_e^k + a_2 \times p_{wf}^k + a_3 \times (p_{wf}^k)^2 \]

\[ q_w^k = b_0 + b_1 \times p_e^k + b_2 \times p_{wf}^k + b_3 \times (p_{wf}^k)^2 \]

\[ q_g^k = c_0 + c_1 \times p_e^k + c_2 \times p_{wf}^k + c_3 \times (p_{wf}^k)^2 \]

Proposed Pressure Modeling for continuous monitoring

\[ (\overline{p})^k = (\overline{p})^{k-1} + d_1 + d_2 \times p_{wf1}^k + d_3 \times (p_{wf1}^k)^2 + d_4 \times p_{wf2}^k + d_5 \times (p_{wf2}^k)^2 \]

Proposed Pressure Drop Modeling for Continuous Monitoring

\[ (p_{wf}^k - p_{th}^k) = l_1 q_o^k + l_2 q_w^k + l_3 q_g^k + l_4 (q_o^k)^2 + l_5 (q_w^k)^2 + l_6 (q_g^k)^2 \]
Closed Loop Asset Management

Outer loop passes the operating point (decisions) to inner loops

Market

Resource Base

Reservoir Model

Development Planning

Scheduler & Optimizer

Supervisory Controller

Regulatory Controller

Data Driven Models

Asset: Wells & Facilities

Actual Conditions

Actual Behavior

Actual Values

Measured Production

Forecast Production

New Target & Execution Plan

Fast loop

Fastest loop

Actual Target & Slower Loop

Real Time Reservoir Management

Real Time Production Optimization
Upper optimization layer passes the best operating point to lower layer

Multilevel Reservoir Control Model

Linear Programming Optimizer -> Net Present Value Function -> Longer Term Reservoir Forecasts

Optimization Level

Regulatory Level

MPC Controller

Reservoir (Simulator)

\[ q_{o,sp}, q_{w,sp}, q_{g,sp} \]

\[ \Delta q_o \]

\[ p_{wf} \]

\[ d \]

\[ q_o, q_w, q_g \]
Attempt to solve a significant reservoir management challenges

Waterflood Management Problem Results

Experimental Base: History-matched Model from El Furrial, HPHT, deep onshore, light oil, 2000 days

**Base Case No control**

- Early water irruption
- High water cut reduced well’s vertical lift
- Further recovery possible at a greater cost

**Controlled Case**

- Water irruption detected and controlled
- Zone shut off permitted better well’s vertical lift
- Recovery accelerated at a minimum cost
Clear benefits from extra little oil but with a lot less effort.

Field-wide life cycle comparison Results

**Oil rate**

- Self-Learning
- Non-Controlled

**Oil Cumulative**

- Self-Learning
- Non-Controlled

**Water rate**

- Self-Learning
- Non-Controlled

**Produced Water Cumulative**

- Self-Learning
- Non-Controlled

**Injected Water Cumulative**

- Self-Learning
- Non-Controlled

\[ \Delta N_p = 500 \text{ Mbbil} \]

\[ \Delta Rev = $5 \text{ Million} \]

\[ \Delta W_p = -18 \text{ MMbbls} \]

\[ \Delta W_i = -19 \text{ MMbbls} \]

\[ \Delta Rev = -$92.5 \text{ Million} \]
Continuous self-learning optimization decision engine

Self Adaptive Reservoir Performance optimization Technique

QP Optimization Loop
\[
\min_{\Delta u} \left\{ \sum_{j=1}^{p} (\hat{y}_{k+j} - y_{SP})^2 + R \sum_{j=1}^{m} \Delta u_{k+j}^2 \right\}
\]
\[
s.t. \quad y_{\min} \leq \hat{y}_{k+j} \leq y_{\max}, j = [1, p]
\]
\[
u_{\min} \leq u_{k+j} \leq u_{\max}, j = [1, m]
\]
\[
u_{k+i} = u_{k+m-l}, i = [m, p]
\]

LP Optimization Loop
\[
\max \left\{ NPV = \sum_{i=1}^{N} f \left( q_o, q_w, q_g, S, \Delta T \right) \right\}
\]
\[
s.t. \quad \begin{align*}
    & P_{\min} \leq P_{k+p} \leq P_{\max} \\
    & q_{\min} \leq q_{k+p} \leq q_{\max}
\end{align*}
\]
\[
\Longleftrightarrow \{ \hat{q}_{o, opt}, \hat{q}_{g, opt}, \hat{q}_{w, opt} \}
\]

LS Optimization Loop
\[
\hat{Y} = X\hat{\theta} + e
\]
\[
\min_{a,b} \left\{ \sum_{i=1}^{N} e_i^2 \right\} \Rightarrow (X^T X)^{-1} X^T Y
\]
\[
\Longleftrightarrow \{ q_{o,G,w} = f_1 \left( p^k, p^{k-1} \ldots q_t^k, q_t^{k-1}, \ldots \right) \\
\]
\[
P_{res} = f_n \left( p^i, p^{i-1} \ldots q_t^k, q_t^{k-1}, \ldots \right)
\]
What benefits does collaborative environments bring?

What are Collaborative Environments?
They can be either:
• Web-based portals
• Interactive collaborative environments
• Automated Workflow Management
• Immersive large scale visualization Rooms
• Real-time, just-in-time and remotely enabled

What are the benefits?
• Access and visualization of large datasets
• Access and visualization of whole asset
• Information stays at its original source
• Shared across disciplines and geographies
### Which applications define RTAM?

<table>
<thead>
<tr>
<th>Visualization</th>
<th>Monitoring</th>
<th>Optimization</th>
<th>Control</th>
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<tr>
<td>Field Measurements</td>
<td>Transforming Data into Better Informed Decision</td>
<td>Advise done by providing asset data awareness</td>
<td></td>
</tr>
<tr>
<td>Indirect Measurements &amp; Inference Models</td>
<td></td>
<td>Advise done by providing report on forecasted values</td>
<td></td>
</tr>
<tr>
<td>Advanced Performance Models</td>
<td></td>
<td>Advise applied automatically over field actuators</td>
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**Optimization Control:**

- **Measurements:** Transforming data into better informed decisions.
- **Advise:** Done by providing asset data awareness.
- **Indirect Measurements & Inference Models:** Provide reports on forecasted values.
- **Advanced Performance Models:** Advise applied automatically over field actuators.
How do we rapidly and smartly adapt to changes?

- Plan, Nurture and Protect Knowledge Communities
- Tie Knowledge and Technology to Business Value
- Promote and Reward Performance Improvement Initiatives
- Promote and Reward Culture of Change
What architecture supports Intelligent Oilfield Operations?

Seamless integration of field hardware with office decision systems …
Real Time Optimization Systems from SPE TIG

Spider Diagram for Prudhoe Bay Integrated Surface & Subsurface Optimization Example, Before and After

Legend

<table>
<thead>
<tr>
<th>Project</th>
<th>Complexity</th>
<th>Adoption</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Initial Pilot with proven value</td>
</tr>
<tr>
<td>1'</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Increased adoption with increased complexity will increase value</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Initial Pilot with proven value and medium complexity</td>
</tr>
<tr>
<td>2'</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Increased value with increased adoption without more complexity</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Initial Pilot with proven value and low complexity</td>
</tr>
<tr>
<td>3'</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Increased value with increased complexity without more adoption</td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Initial Pilot with proven high value high complexity and low adoption</td>
</tr>
<tr>
<td>4'</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Project downsized to reduce complexity and value reduced</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High value project fully deployed and low complexity. No further growth</td>
</tr>
<tr>
<td>6</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low value initial pilot with medium complexity. Project abandoned.</td>
</tr>
</tbody>
</table>
Intelligent Oilfield Operations - Technology Status

Saputelli et al., 2004
What are the opportunities?

**Integrated Asset Management and Optimization:**
- Well location, scheduling, spacing and quantity
- Well completion and vertical lift strategy
- Secondary and enhanced oil recovery design operation
- Surface facilities & total fluid handling capacity → target plateau
- Resource allocation (Capex, Opex, Gas Compression)
- Plant and equipment overhaul schedules
- Pipeline scheduling availability
- Portfolio Optimization & Resource base planning

**Production Operations Optimization**
- Well profile management (coning, cusping, well management)
- Field and well level gas lift optimization
- Hydrocarbon and other fluids transportation
- Surface de-bottlenecking and continuous field-optimization
- Candidate selection for stimulation and intervention

**Drilling & Completion Optimization**
- Well construction design (materials, time, resources)
- Drilling operations (hydraulics, trip time, non-productive time)
What are the blockers for Intelligent Oilfield Operations?

Don’t have the *right* data:
- either low quality or insufficient quantity or taken too infrequently.

Don’t have the *integrated software tools*
- to properly model the specific system the way we would like it. “waiting on common data standards“.

It seems like a good idea, but would probably be too expensive.

We cannot handle change management well enough
- and so a system will soon be out of date.

Lack of training in automated optimization engineering

Poor communication layers across disciplines involved.

Lack of resources (time and financial) to focus on real-time optimization.

Contentment with the past way of doing things.
Why do we think is not used more?

Existing tools are not well understood

Misunderstanding about how emerging technologies fit in with existing field developments.

The inability to build a *convincing* business case for management
Conclusions

• Intelligent Oilfield Operation’s Vision is to efficiently use of data and information to generate opportune decisions in regards to optimum exploitation

• IOO’s vision capitalizes in these elements:
  • Integration of measuring, SS models and actuation
  • Front-end engineering planning for accurate prediction
  • Remote collaboration of experts and data sharing
  • Rapid adaptation of technologies

• IOO’s Technologies are available, business case fully justified.

• Feasibility of IOO demonstrated through a number of cases studies