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The Economics of 4D Reservoir Management

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Abstract

The oil industry is still staggering from the recent price collapse, with management energy focused on cutting costs and improving return on capital employed (ROCE). The major fiscal problem of the energy business is that it is not competitive as an investment vehicle when compared to other growth industries such as computing, the internet, and biomedicine, because our ROCE is so poor. While new exploration hotspots like offshore west Africa and the ultra deepwater Gulf of Mexico offer the promise to return >30% ROCE, refining and marketing is a drag at <5%. The industry's hope to return from its current "contrarian" financial position to become a sound fiscal industry rests in the delivery on promise from the high return offshore areas around the globe. It is not enough to discover and prove out large reserve numbers anymore in these giant and super giant oil fields. As often as not, survival of the oil company owners rests on delivering to market at a 60% or higher recovery rate. When the economics of 4D Reservoir Management are considered in a stochastic portfolio model of future cash flow, various price scenarios can be considered quantitatively in terms of the relative contributions of each large field to the company's overall success. It becomes clear that high recovery rates are required to balance risk and reward sufficiently. However, if cost cutting models are used that exclude 4D Reservoir Management from future development scenarios for these fields, cash flow shortfalls result in all but the most optimistic future price scenarios.

Thus, reservoir development plans that deliver cash when it is needed for a company are required, and in all-important fields, 4D Reservoir Management becomes essential. The costs of repeated acquisition of 3D seismic surveys and continuous downhole instrumentation and monitoring become cost effective near term investments when considered in this long-term cash flow framework.

There are several examples from key fields in prime offshore areas where it has already been demonstrated that 4D Reservoir Management is a key to economic success of the basin. We will review a Gulf of Mexico field where 4D seismic monitoring produced significantly different drainage patterns from those expected, and early on in the life of the field, as well.

Extraction of as much of the discovered oil and gas in known reservoirs is a critical capability that will be required to balance supply/demand in the 21st century. 4D Reservoir Management returns substantial capital versus that invested, and therefore is an essential component of responsible Business Unit management in the modern age.

Introduction to Portfolio Management (PM)

Oil and gas production companies make money based upon on their skills in identifying a portfolio of properties and utilizing technologies to discover, produce, and sell oil and gas produced from those properties in an optimal manner. The key ingredient to improved business performance is portfolio management, which allows a company to present the performance of all its producing properties and exploration targets in a normalized way. Business metrics such as earnings, production volumes, net cash flow, and reserves additions can be balanced to obtain a maximum likelihood of successful execution of the overall business plan of the company. Fluctuations in the in the market can be evaluated statistically so that hedges, trades and options can be evaluated in a quantitative sense. Cash flow can be understood so that the true value of each property can be determined from its **INTERACTION** with all other properties in the portfolio. The efficient frontier (optimal risk/reward position for the business plan) of the portfolio can then be determined and business strategies determined. A property producing critical cash for exploration plays may be valued considerably higher than the "book value" determined by an audit of its remaining proven and probable reserves. Correspondingly, a property of high audited value may be a tremendous burden to the overall portfolio, and consequently may carry a substantially lower valuation.

Understanding how the business operates from day-to-day then forms the foundation for improvements to the production capabilities of individual properties. Superior production performance rests in the capability to know how,

when, and in what order to execute technologies within the overall business plan of the oil company.

We have significant industry experience with the combination of portfolio management and 4D enhancements to production capabilities for many large oil companies. We founded and operated the Lamont Portfolio Management (LPM) consortium at Columbia University from 1997 through 1999. The LPM has installed its software and successfully worked to help implement PM with its 11 member companies. The LPM software stochastically computes and visualizes the "Efficient Frontier" in risk/reward space from multiple dimensions of business attributes and target performance metrics. It evaluates the interdependence of all the company's production properties, exploration opportunities, and merger/acquisition targets simultaneously and provides a mechanism for evaluating possible performance outcomes 10 years into the future.

Oil Company E&P Performance

The E&P business is in the midst of a major transformation from an emphasis on cost cutting to more diverse portfolio management practices, and the industry has found that it is not easy to simultaneously optimize net-present-value (NPV), return-on-capital invested (ROCE) and long-term growth

Recent performance of companies varies widely, from those that both find abundant new exploration and exploitation reserves and produce their known fields well to those that are only good at either production or exploration In fact, some companies have not had much recent success in either exploration or exploitation growth. Though the balance sheets of the latter companies look fine for the near term (and share prices are holding), they are neither booking sufficient new reserves to replace those being produced, nor are they efficiently exploiting the fields they own.

. The LPM software and softside computational and human interactive tools must assess the risk/reward tradeoffs inherent in the upstream linkages between 1) the application of advanced technologies to improve success in exploration and in exploitation (reservoir evaluation, drilling, producing, and delivery to market) and 2) the maximization of both short- and long-term profitability.

PM merged with Technical Suitability Matrix (TSM)

PM tools must be combined with software that evaluates the appropriateness of the various technologies available to the industry to solve the specific production problems relevant to the performance of individual fields. Technologies are related to reservoir characterization, drilling, producing, and integration. They must be selected based upon their suitability to boost specific performance attributes that produce cash and/or grow reserves, such as the petroleum system in exploration, and reserves definition, drilling success, producability of wells, and production to market in exploitation. Only technologies that are suitable to specific attributes accrue true benefit to the portfolio as a whole.

How does a company make the correct technology choices? Software is needed that allows the customer to rate the suitability of the various technologies available to each field. These, in turn, are correlated to attributes specific to the performance of their portfolio on the web. The Technology Suitability Matrix (TSM) computes correlation coefficients for the most suitable technology/business attribute pairs in the matrix). The tool helps the client select and prioritize where to use which technologies, in what order, and when. The TSM has been constructed to answer other business questions as well, such as the following:

1. Which technologies are required in what fields to meet a specific set of complex business goals such as NPV growth, ROCE, and reserves growth?

2. Which technologies enable an advanced understanding of the complex flow of hydrocarbons necessary to maximize drainage from the reservoir to wellbores in those fields of critical importance to the portfolio?

3. Which fields are most in need of applied rock physics to analyze and understand seismic and well log responses in terms of porosity, clay content, fluid saturation changes over time, and other physical properties that are critical to meeting portfolio goals?

4. Which fields require exotic well trajectories, wellbore damage repair, and/or improved remedial stimulation to make the flow rates required by the business plan?

5. Which wells require changes to drilling and completion fluids and treatments for asphaltenes and paraffin's that are costing the portfolio cash that might be critically needed by the business goals?

6. Which water and/or gas floods need to be modified to correct for anomalous fluid front movements that are inhibiting overall field performance?

PM and TSM Merged into 4D Reservoir Management

The tracking of fluid drainage over time is a required condition for efficient reservoir monitoring. 4D (time-lapse) seismic differencing holds great promise as the keystone to an e-based integrated reservoir management strategy that is able to image changes not only within a reservoir but within the stack of reservoirs that make up most of the oil and gas fields of the world. Yet there are major components of 4D seismic monitoring that are only just being developed by the industry. Field acquisition is still centered on reacquisition using 3D methodologies; processing and interpretation are focused on normalization and differencing of time lapse data itself; and seismic modeling is 1D and 2D, acoustic, and built around one reservoir at a time.

Not only would the reservoir stack be simulated from a fluid flow perspective, but the drainage changes would be fed into a 3D, elastic seismic modeling program that could simulate seismic amplitude changes accurately enough to be realistically compared to real 4D seismic field data differences. An optimizer would then reconcile the differences between the differences. That is, the time-lapse differences between observed and computed seismic and fluid flow models and data would converge to the best view of the

real changes occurring in oil and gas fields that the industry has so far been able to produce.

The Systems Architecture to support a Web-enabled 4D Reservoir Management System that incorporates PM, TSM, and 4D reservoir monitoring requires:

- A means of integrating legacy codes that represent software developed using methodologies that were the "right way" at the time of their implementation but would not be the way if done today.
- A basis for developing new applications that can make use of current notions of software development tools and methodologies, but can also be a basis towards adapting future tools and methodologies.
- A rational approach to data in its multitude of formats.
- A way of interacting with distributed computational codes (often-parallel codes) in various degrees of coupling to the overall architecture.
- A means of keeping track of state information about the workflow in the system in a way that is digestible to the user.
- A system architecture that does not suffocate under its own complexity.

The e-reservoir "Loop of the Future"

A. Rapid Analysis and Inversion workflow for non-linear inversion of 2 or more 3D seismic volumes, their time-depth conversion, normalization and differencing.

B. Workflow for well log preparation and depth-time conversion.

C. Workflow for 4D Reservoir Characterization of the two seismic volumes.

D. Export to a MultiMesh Earth Model.

E. Fluid flow simulation in a large Reservoir Simulator.

F. 3D elastic seismic modeling phase to generate 4D synthetic seismic model.

G. Export to seismic processing system for migration.

H. Differencing of 4D models versus real seismic and analysis of difference-of-differences.

I. Optimizer identifies changes in physical properties of reservoirs to more closely match fluid withdrawal, pressure changes and seismic differences.

J. "Go To" loop back to E.

We believe that extensive deployment of the superstructure for 4D Reservoir Management will allow the industry to develop a sound, diversified portfolio of properties that can be optimized to produce excellent business return as measured against any set of Wall Street business performance metrics.

Conclusions

It is evident to us that the portfolios of most oil companies are not optimal in a modern business sense. We believe that use of a real-time 4D-reservoir management system such as that described above will oil companies to:

1. Combine a substantial range of properties and exploration plays into a single portfolio, analyze the interdependencies of the properties, and determine their true worth to the company,

2. Determine the efficient frontier of the new business, and shed properties that do not fit into a new business plan designed to optimize business performance, and

3. Introduce new techniques and technologies into the newly reconstituted portfolio to maximize production and produce profits that are at least 35% higher than the sum of that from the independent properties before they were managed as a unit.

Acknowledgments

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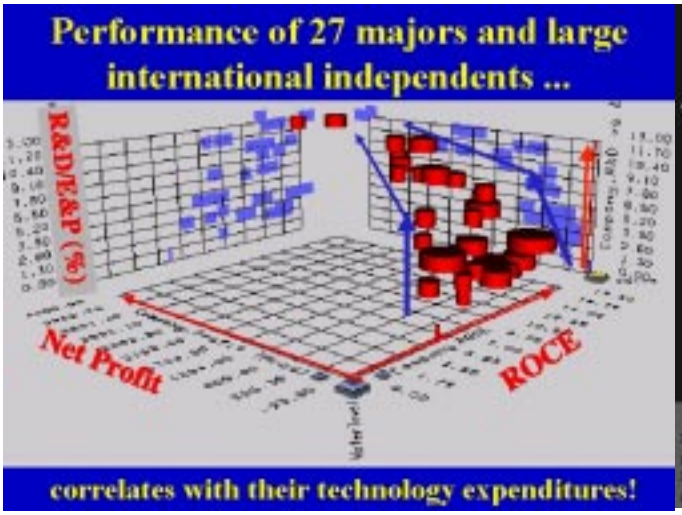
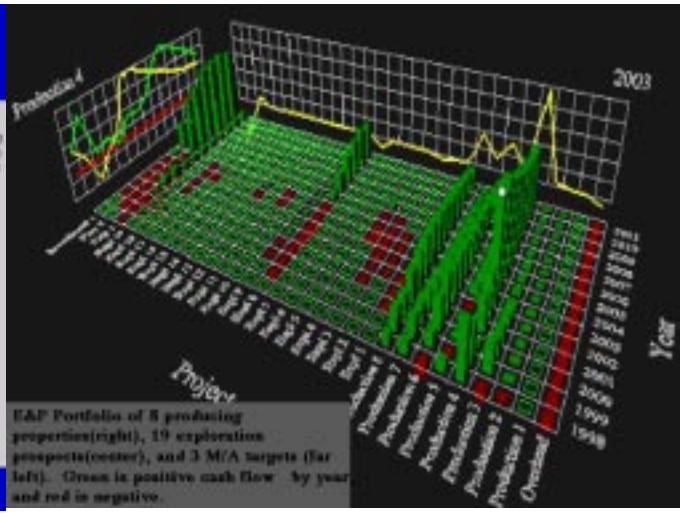
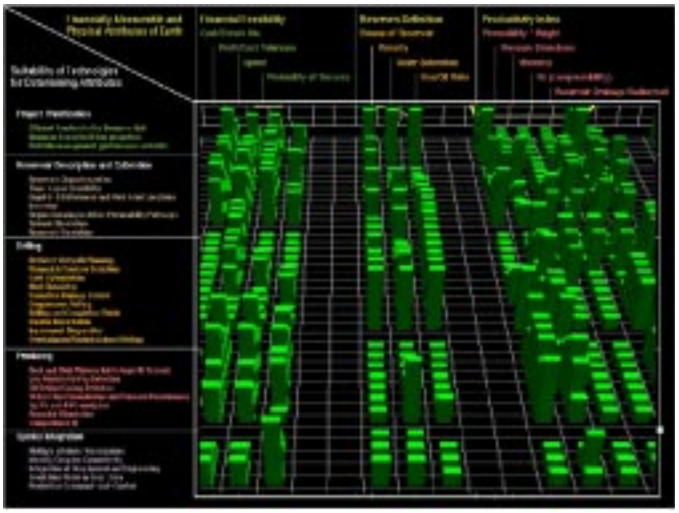
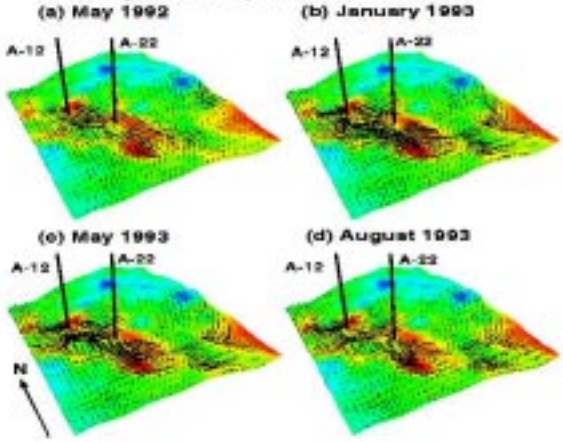


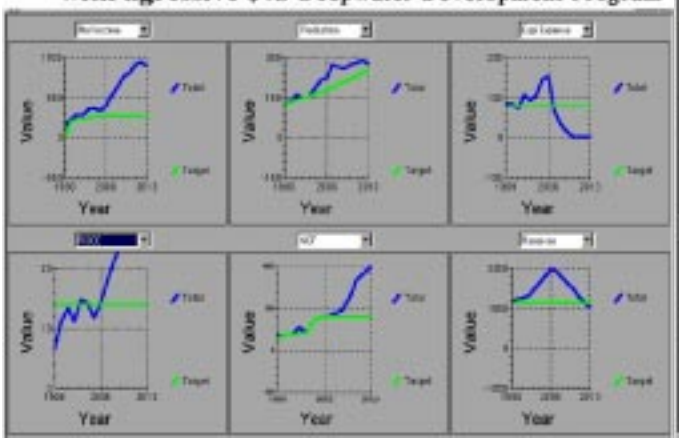




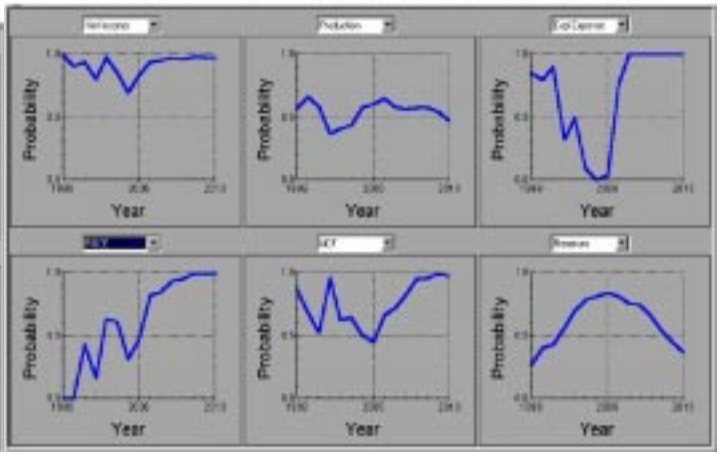
From 4D monitoring of the migration of fluid fronts over time comes Reservoir Management and Optimization of Performance

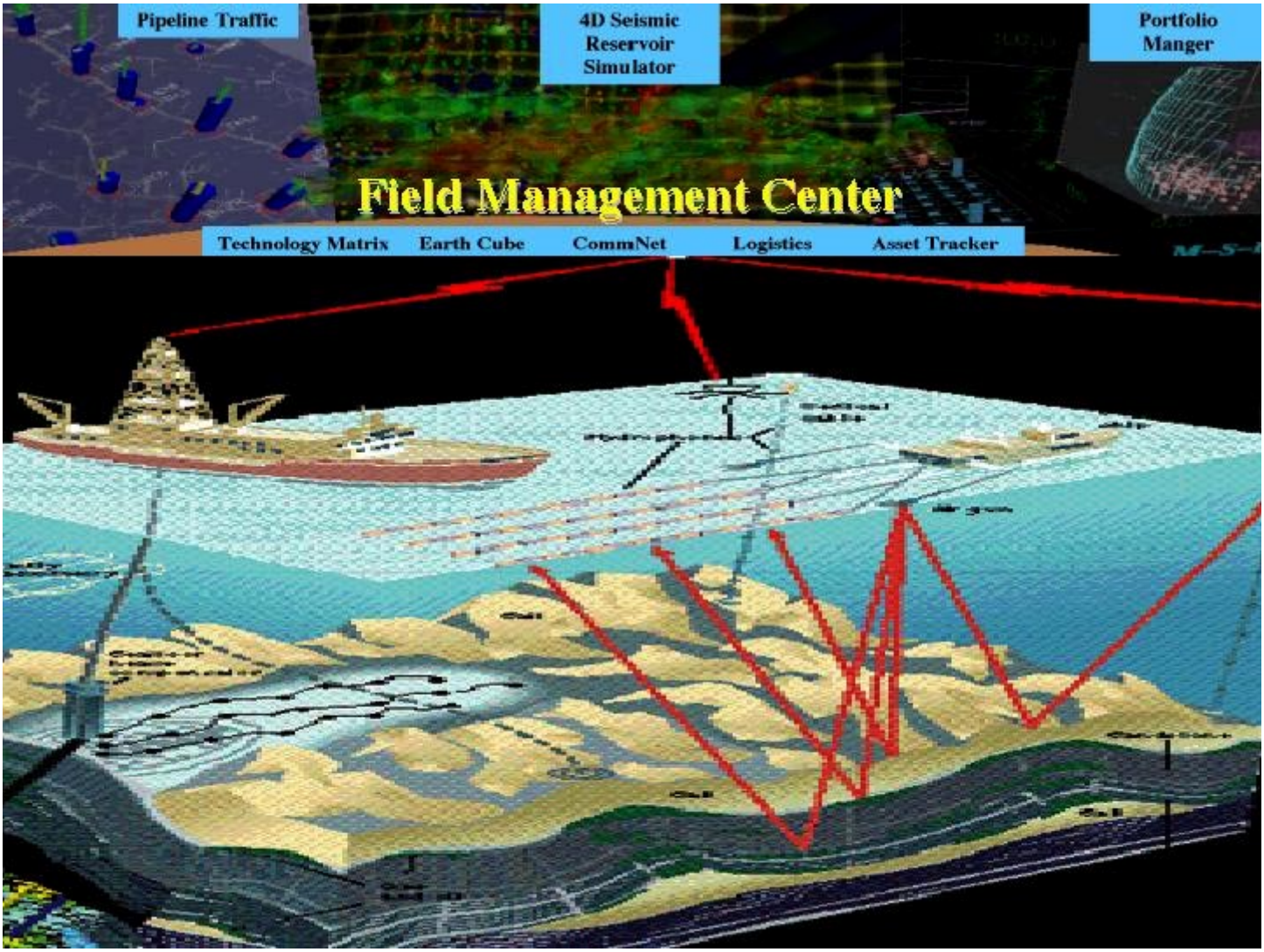


Predicted Portfolio Results
with agressive $4B Deepwater Development Program



Probability of Achieving
Metrics with Aggressive Development Strategy




Pipeline Traffic
4D Seismic Reservoir Simulator
Portfolio Manger
Field Management Center
Technology Matrix
Earth Cube
CommNet
Logistics
Asset Tracker