Top-Down Intelligent Reservoir Modeling (TDIRM); A New Approach in Reservoir Modeling by Integrating Classic Reservoir Engineering with Artificial Intelligence & Data Mining Techniques

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Summary

Traditional reservoir simulation and modeling is a bottom-up approach. It starts with building a geological model of the reservoir followed by adding engineering fluid flow principles to arrive at a dynamic reservoir model. The dynamic reservoir model is calibrated using the production history of multiple wells and the history matched model is used to strategize field development in order to improve recovery.

Top-Down Intelligent Reservoir Modeling approaches the reservoir simulation and modeling from an opposite angle by attempting to build a realization of the reservoir starting with well production behavior (history). The production history is augmented by core, log, well test and seismic data in order to increase the accuracy and fine tune the Top-Down model. The model is then calibrated (history matched) using the most recent wells as blind dataset. Although not intended as a substitute for the traditional reservoir simulation of large, complex fields, this novel approach can be used as an alternative (at a fraction of the cost and time) to traditional reservoir simulation in cases where performing traditional modeling is cost (and man-power) prohibitive. In cases where a conventional model of a reservoir already exists, Top-Down Intelligent Reservoir Modeling should be considered a complement to, rather than a competition for the traditional technique. It provides an independent look at the data coming from the reservoir/wells for optimum development strategy and recovery enhancement.

Top-Down Intelligent Reservoir Modeling is an elegant integration of state-of-the-art in Artificial Intelligence & Data Mining (AI&DM) with solid reservoir engineering techniques and principles. It provides a unique perspective of the field and the reservoir using actual measurements. It provides qualitatively accurate reservoir characteristics that can play a key role in making important and strategic field development decisions. In this article, principles of Top-Down Intelligent Reservoir Modeling are discussed along with an actual cases study.

Traditional Reservoir Simulation & Modeling

Reservoir simulation is the industry standard for reservoir management. It is used in all phases of field development in the oil and gas industry. The routine of simulation studies calls for integration of static and dynamic measurements into the reservoir model. Full field reservoir simulation models have become the major source of information for analysis, prediction and decision making. Traditional reservoir simulation and modeling is a bottom-up approach that starts with building a geological (geo-cellular) model of the reservoir. Using modeling and geo-statistical manipulation of the data the geo-cellular model is populated with the best available petrophysical and geophysical information at the time of development. Engineering fluid flow principles are then added and solved numerically so as to arrive at a dynamic reservoir model. The dynamic reservoir model is calibrated using the production history of multiple wells in a complex process called history matching and the final history matched model is used to strategize the field development in order to improve recovery. Traditional reservoir simulation and modeling is a well understood technology that usually works well in the hand of an experienced team of engineers and geoscientists.

Characteristics of the traditional reservoir simulation and modeling that is relevant to this article and are addressed by Top-Down Intelligent Reservoir Modeling are:

1. It takes a significant investment (time and money) to develop a geological (geo-cellular) model to serve as the foundation of the reservoir simulation model.
2. Development and history matching of a reservoir simulation model is not a trivial process and requires modeler and geoscientists with significant amount of experience.
3. It is an expensive and time consuming endeavor.
4. A prolific asset is required in order to justify a significant initial investment that is required for a reservoir simulation model.

TOP-DOWN INTELLIGENT RESERVOIR MODELING AS AN ALTERNATIVE

Top-Down Intelligent Reservoir Modeling approaches the reservoir simulation and modeling from an opposite angle by attempting to build a realization of the reservoir starting with well production behavior (history). The production history is augmented by core, log, well test and seismic data in order to increase the accuracy of the Top-Down modeling technique. Although not intended as a substitute for the conventional reservoir simulation of large, complex fields, this unique approach to reservoir modeling can be used as an alternative (at a fraction of the cost) to traditional reservoir simulation and modeling in cases where performing conventional modeling is cost (and man-power) prohibitive. In cases where a conventional model of a reservoir already exists, Top-Down modeling should be considered as a compliment to, rather than a competition for the conventional technique, to provide an independent look at the data coming from the reservoir/wells for optimum development strategy and recovery enhancement.

Top-Down Intelligent Reservoir Modeling starts with well-known reservoir engineering techniques such as Decline Curve Analysis, Type Curve Matching, History Matching using single well numerical reservoir simulation, Volumetric Reserve Estimation and calculation of Recovery Factors for all the wells (individually) in the field. Using statistical techniques multiple Production Indicators (3, 6, and 9 months cumulative production as well as 1, 3, 5, and 10 year cumulative oil, gas and water production and Gas Oil Ratio and Water Cut) are calculated. These analyses and statistics generate a large volume of data and information that are spatio-temporal snap shots of reservoir behavior. This large volume of data is processed using the state-of-the-art in artificial intelligence and data mining (neural modeling[1], genetic optimization[2] and fuzzy pattern recognition[3]) in order to generate a complete and cohesive model of the entire reservoir. This is accomplished by using a set of discrete modeling techniques to generate production related predictive models of well behavior, followed by intelligent models that integrate the discrete models into a cohesive picture and model of the reservoir as a whole, using a continuous fuzzy pattern recognition algorithm.

The Top-Down Intelligent Reservoir Model is calibrated using the most recent set of wells that have been drilled in the field. The calibrated model is then used for field development strategies to improve and enhance hydrocarbon recovery.

DETAILS AND AN EXAMPLE OF TOP-DOWN MODELING

Top-Down Modeling is an elegant integration of state-of-the-art in Artificial Intelligence & Data Mining (AI&DM)[1-3] with solid reservoir engineering techniques and principles. It provides a unique perspective of the field and the reservoir using actual measurements. It provides qualitatively accurate reservoir characteristics that can play a key role in making important and strategic field development decisions. The key to the top-down modeling is the integration of reservoir engineering with Artificial Intelligence & Data Mining (AI&DM). Following is a brief summary of several components of this approach to reservoir modeling and management:

a. ***Decline Curve Analysis:*** Conventional hyperbolic decline curve analysis is performed on oil, gas and water production data of all the wells. Intelligent Decline Curve Analysis[4] is used to model some production data such as GOR and Water Cut that does not usually exhibit a positive but rather a negative decline.
b. ***Type Curve Matching:*** Using the appropriate type curves, production data from all wells are analyzed. Special techniques are used to remove the inherent subjectivity associated with type curve matching process.
c. ***History Matching:*** History matching is performed on all individual wells using a single well radial numerical simulation model.
d. ***Production Statistics:*** General statistics are generated based on the available production data such as 3, 6, 9 months cumulative production and one, three, five and ten years cumulative productions. Similar data is generated for Gas Oil Ratio and water cut.
e. ***Volumetric Reserve Estimation:*** Using Voronoi[5] graph theory in conjunction with well logs volumetric reserves are estimated for each well, individually.
f. ***Recovery Factor Calculation:*** Using the results of Decline Curve analysis and Volumetric Reserve Estimation, a well-based Recovery Factor is calculated for all wells, individually. A field-wide Recovery Factor is also calculated. This would be an item that will be optimized in the consequent steps of the analysis.
g. ***Discrete Predictive Modeling:*** Results of the abovementioned analyses are a wealth of data and information that are generated based on individual wells. This information is indicative of reservoir/well behavior at specific time and space throughout the life of the reservoir. Using AI&DM techniques discrete, intelligent, predictive models are developed based on the large amount of data and information that has been generated. The predictive models represent all aspects of reservoir characteristics that have been analyzed.
h. ***Continuous Predictive Modeling:*** Using two-dimensional Fuzzy Pattern Recognition (FPR) technology[4], discrete predictive models are fused into a cohesive full-field reservoir model that is capable of providing a tool for integrated reservoir management.
i. ***Model Calibration:*** The full field model is calibrated based on classifying the reservoir into "most" to "least" prolific areas, prior to be used in the predictive mode. This is done using the latest drilled wells in the field. This practice is an analogy of history matching of the conventional reservoir simulation models. The calibrated model can then be used in predictive mode for field development strategies.

j. ***Field Development Strategies:*** Performing economic analysis, while taking into account the uncertainties associated with decision making, multiple field development strategies are examined in order to identify the optimum set of operations that would result in recovery enhancement. This process includes identification of remaining reserves, sweet spots for infill drilling as well as under-performer wells

Year	Number of Well Drilled
1986	4
1987	6
1988	15
1989	134
1990	99
1991	72
1992	13
1993	5
1994	0
1995	1
Total	349

Table 1. Number of wells starting production in each of the years.

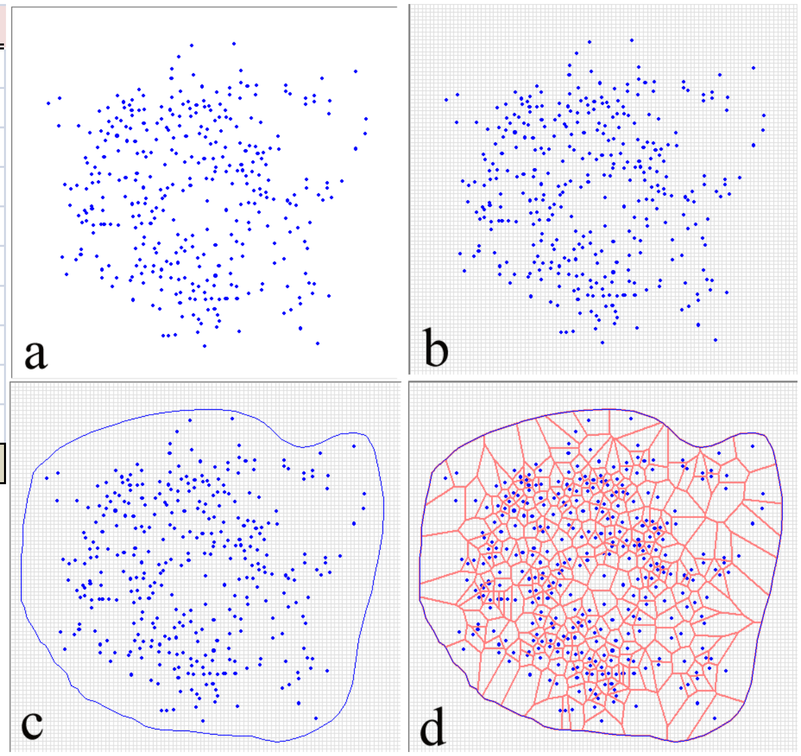

Figure 1. Generating the Voronoi cells for the wells in the Carthage field, Texas.

One of the most important advantages of Top-Down modeling is its ease of development. It is designed so that an engineer or a geologist with a Bachelor's degree will be able to comfortably develop a Top-Down model in a relatively short period of time with minimum amount of data. The disadvantage of Top-Down modeling is that it cannot be performed on "any" field. It is designed for fields that have at least 50 wells and about 5 to 7 years of production.

Location and monthly production rate data for all wells and well logs (not necessary for all wells) are the minimum data requirement for the Top-Down modeling. Figures 1,2 and 3 are a short summary of the processed used to complete a Top-Down model. These figures are related to a Top-Down modeling study that was performed on part of Carthage field in Texas that included 349 wells. These wells were drilled from 1986 to 1995. Table 1 shows the number of wells that were drilled on any given year since 1986. Figure 1 shows the well locations, followed by identification of boundary and the Voronoi grids for all the wells in the analysis. Once the Decline Curve Analysis and other steps that were mentioned above were completed, the discrete modeling and fuzzy pattern recognition are performed. The distribution of first three months of production as well as the 5 year cumulative production are (results of discrete predictive modeling) shown in Figure 2. Figure 3 shows the results of fuzzy pattern recognition. The sweet spots in the field are shown with the dark brown color. The Relative Reservoir Quality (RRQ) is indicated by the colors in this figure. Higher quality of the reservoir are indicated with darker color. Figure 3 shows the depletion in the reservoir as the sweet spot shrinks between 3 months and 5 years (from left to right). This provides an indication of depletion and a guide on where to drill the next wells in this field.

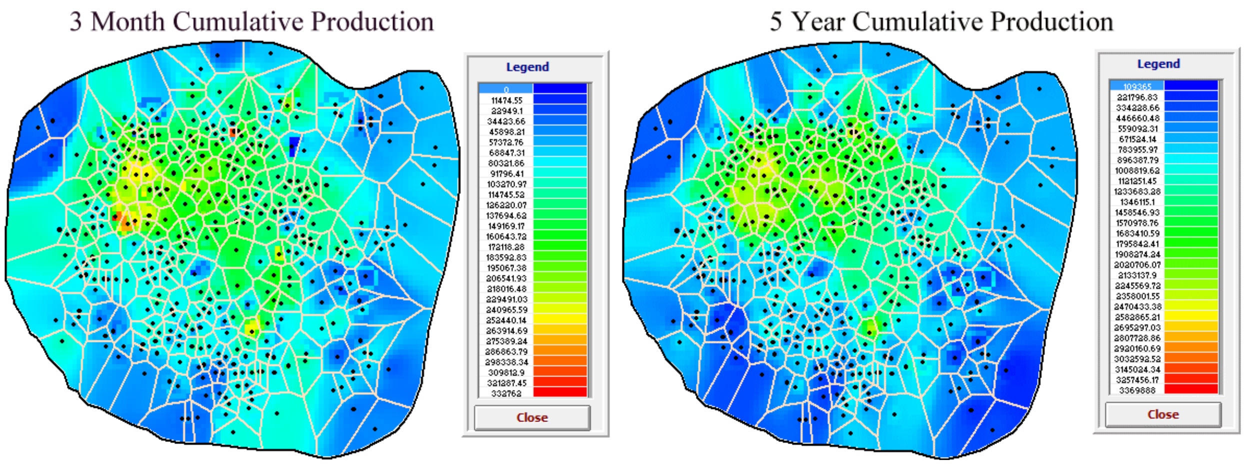

Figure 2. Results of discrete predictive modeling showing the distribution of first 3 months and 5 year cum. production for the entire field.

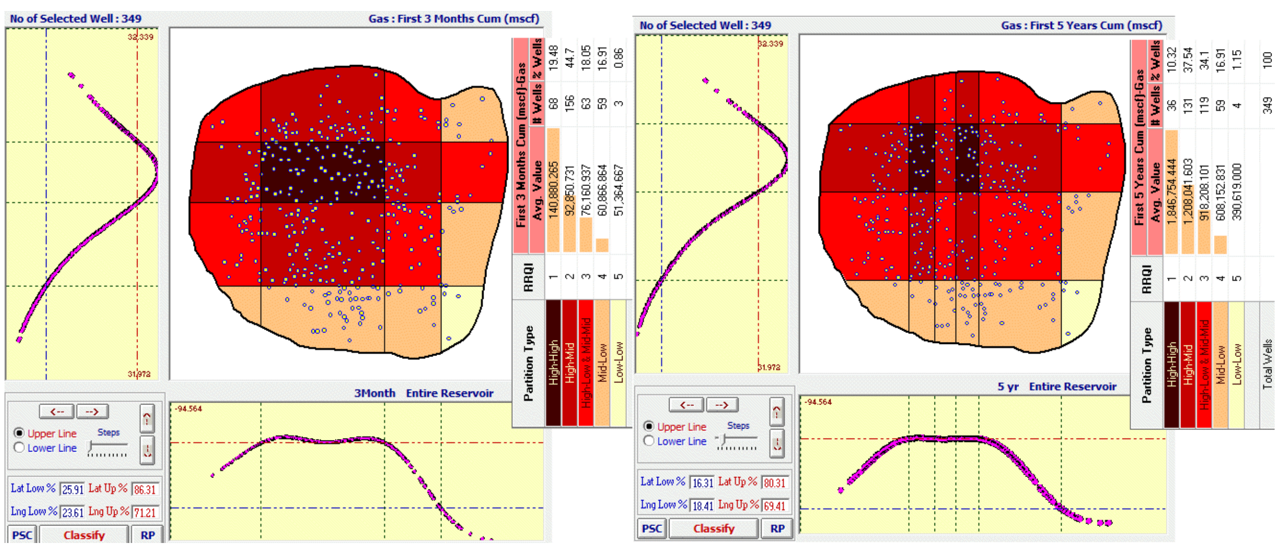

Figure 3. Results of Fuzzy Pattern Recognition showing the sweet spots in the field for the first 3 months (left) and 5 year cum. production (left).

To calibrate the Top-Down model the most recent wells are removed from the analyses. Nineteen wells that were drilled during years 1992 – 1995 were removed. The model is developed using the remaining 330 wells. The objective was to see if the Top-Down model can predict the 5 year cumulative production for these 19 wells (blind data set). The results are shown in Table 2. In this table the five Relative Reservoir Quality Indices (RRQI) are shown as well as the model results that indicates the prediction for the blind wells. As indicated in this table the Top-Down model predicted that the average 5 year cumulative production for wells drilled in the RRQI "1" (the darkest areas in Figure 3) will be more than 1.54 BCF. There were 4 wells drilled in RRQI "1" during 1992-95 and the average 5 year cumulative production for these wells was 1.81 BCF (correct prediction). Furthermore, the Top-Down model predicted that the average 5 year cumulative production for wells drilled in the RRQI "2" will be between 1.10 and 1.54 BCF. As shown in Table 2 there were 3 wells drilled in RRQI "2" during 1992-95 period and the average 5 year cumulative production for these wells was 1.49 BCF (correct prediction). For RRQI "3" the Top-Down model over estimates the outcome slightly. It predicted that the average 5 year cumulative production for wells drilled in the RRQI "3" will be between 750 MMSCF and 1.10 BCF while the five wells drilled in RRQI "3" in that period had an average 5 year cumulative production of 1.28 BCF. The Top-Down model predicted that the average 5 year cum. for the 7 wells drilled in the RRQI "4" will be between 427 and 750 MMSCF and it turned out to be 464 MMSCF (correct prediction).

5 Years Cumulative Production (MSCF)					
	Model Results			Wells (1992-1995)	
RRQI	More Than	&	Less than	Average 5 Yr Cum.	No. of Wells
1	1,541,433			1,808,466	4
2	1,104,668	&	1,541,433	1,490,062	3
3	750,285	&	1,104,668	1,282,069	5
4	427,315	&	750,285	464,190	7
5			427,315	Total	19

Table 2. Results of Top-Down modeling.

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