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# Technology Optimizes Lateral Spacing

By Shawn DeVerse
and Stefan Maus

DENVER–Drilling the optimal number of horizontal wells to efficiently drain ultralow-permeability reservoirs is critical to achieving economic value in shale and tight oil plays. In any development project, the goal is to drill the fewest number of horizontal wells required to maximize reservoir drainage. That means spacing laterals at a distance sufficient to minimize overlapping drainage areas while remaining close enough to avoid stranding any reserves.

Because drainage areas are limited to fracture propagation distances, drilling laterals too far apart will result in inadequate production performance and reserves recovery. On the other hand, developing acreage with laterals spaced too tightly will increase costs, create wellbore interference issues, and add logistical challenges without necessarily boosting production or recovery.

However, optimizing lateral spacing is challenging. Many variables must be considered, including hydraulic fracture geometry and reservoir properties. One variable that often is overlooked is wellbore positional uncertainty caused by inaccurate directional surveying. Standard measurement-while-drilling directional surveying is subject to numerous error sources that can be estimated by the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA) error model. These error sources are quantified and modeled as three-dimensional ellipsoids of uncertainty (EOU) that provide drillers a mechanism to measure wellbore trajectory positional uncertainty.

The ISCWSA error model can be used to predict the statistical distribution of wellbore positions to gain an understanding of how far actual well paths may deviate from their surveyed positions. Furthermore, some of the greatest error sources represented in the error model can be reduced significantly using in-field geomagnetic referencing (IFR) and multistation analysis (MSA) to improve MWD surveying accuracy. Performing advanced survey management analysis on raw MWD data and correcting identified systematic errors in real time improves the accuracy of well placement as a wellbore is drilled.

To reliably determine the optimal lateral well spacing, positional uncertainty should be applied to reservoir simulations and production models. Furthermore, applying IFR/MSA survey corrections to standard MWD surveying can improve horizontal wellbore positional accuracy by 50-60 percent, leading to better decisions for optimizing field development and maximizing the value of each lateral.

Positional uncertainty can be modeled by 3-D EOUs at each survey point in the well path, representing a statistical distribution of where the actual survey may exist. EOUs are computed from tool codes using anti-collision software. ISCWSA's Operator's Wellbore Survey Group has published a consolidated set of tool codes to represent most surveying methodologies. In one example from a shale play in Texas, evaluating a lateral longer than 10,000 feet planned with standard MWD at various azimuths showed 259-439 feet of expected lateral deviation at the bottom-hole location. Applying IFR/MSA to the MWD survey reduced deviation to 129-173 feet.

## IFR And MSA

IFR is a means of predicting the local magnetic field at a specific geographic location. It can be used to support MWD operations as a reference frame for magnetic measurements. IFR accounts for three of the four contributing factors of the geomagnetic field:

Main field (generated by the Earth's core);

Crustal field (magnetic minerals in the Earth's crust); and

Steady external field (generated by charged particles flowing in the Earth's atmosphere).

The remaining contribution to the geomagnetic field is the magnetic disturbance field generated by electric currents in near-Earth space. The disturbance field is accounted for by IFR measurements and corrections.

An IFR model must capture a wide spectrum of wave lengths in the geomagnetic field. Satellite measurements account for the long-wavelength (266-2,500 kilometer) crustal field as well as the main field, secular variation and steady external field. A local magnetic survey provides the shorter wavelengths by accurately mapping local crustal field anomalies.

To provide a model that is continuous across the geomagnetic spectrum, the local magnetic survey is extended by merging it with a larger regional survey. The merged grid is then further extended to cover the longest wavelengths by merging with satellite measurements. The merging of these different datasets must be evaluated at the same altitude and must make seamless boundary transitions.

However, the local magnetic survey only specifies the total strength of the magnetic field vector, and MWD requires accurate modeling of the direction of the magnetic field vector. It is possible to accurately determine the direction of the magnetic field by representing its vector as the gradient of a scalar potential using ellipsoidal harmonic basis functions.

This method was used to create IFR models covering both the Permian Basin and Eagle Ford Shale. Figure 1A shows the input data used for the Permian IFR model. It was created by merging three local aeromagnetic surveys. Two commissioned surveys cover the majority of the area, and publicly available data were used to bridge the gap between the two surveys. Figure 1B shows the input data for the IFR model covering a large part of the Eagle Ford. It was created from a single local aeromagnetic survey.

As a result of this work, IFR values for these areas have been made available for horizontal drilling operations.

By comparing the measured total magnetic field, magnetic dip angle and total gravity field from multiple survey stations against the theoretical values obtained from an IFR model and global acceleration reference model, systematic bias and scale errors can be resolved for MWD accelerometers and magnetometers. This enables corrections to be applied to raw MWD measurements to reduce uncertainties from instrument calibration, magnetic drill string interference, and magnetic mud.

Since magnetic drill string interference is one of the largest contributors to azimuth error, correcting for it substantially reduces positional uncertainty. If the BHA components are strongly magnetized while drilling, MSA-corrected surveys may result in a significant change in a wellbore's position. Because MSA relies on the accuracy of the magnetic reference model for determining MWD error, it is critical to use an IFR model to achieve the most accurate survey analysis.

### Permian, Eagle Ford Results

Advanced survey analysis was performed on 138 wells drilled in the Permian and Eagle Ford. For the majority of these wells, survey analysis was performed in real-time while drilling to steer the well path according to the well plan. The process for real-time survey analysis occurred with each survey station. When an MWD survey was shot, the raw measurements were uploaded to a Web application, where the survey underwent a validation process to ensure it was free from gross errors.

Once a survey passed the initial validation, it was stored in a cloud-hosted database and accessed by analysts in a remote operating center to further analyze it for systematic errors such as

**FIGURE 1A**

**Permian Basin IFR Model**

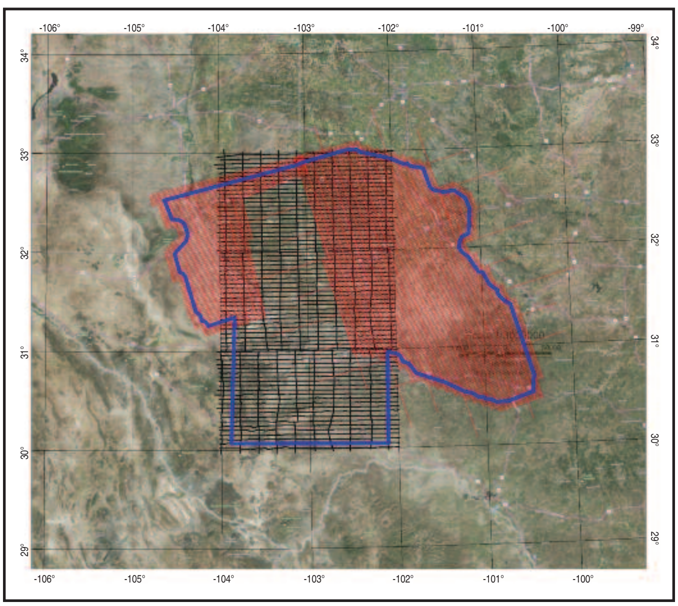



**FIGURE 1B**

**Eagle Ford Shale IFR Model**

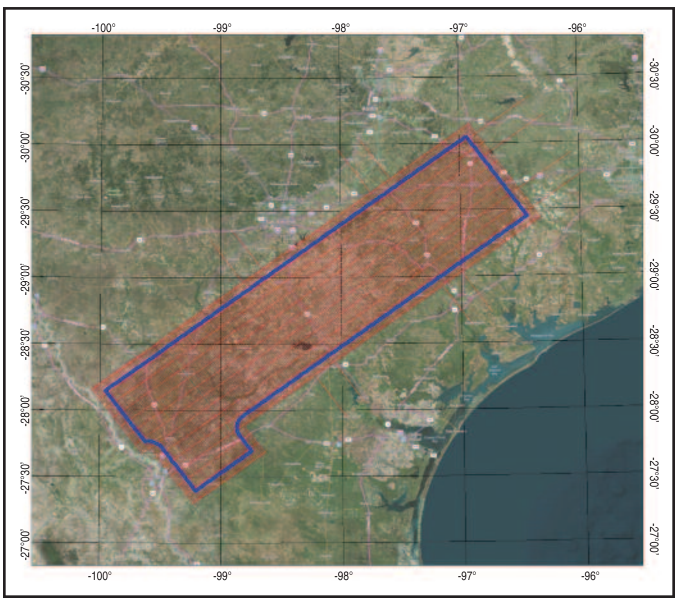
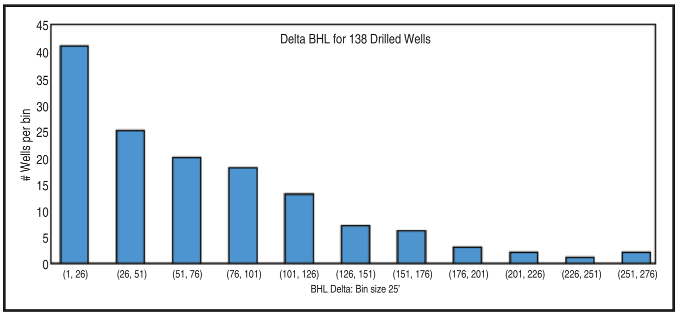


**FIGURE 2**

### Original versus Corrected Difference In Bottom-Hole Location Horizontal Distance



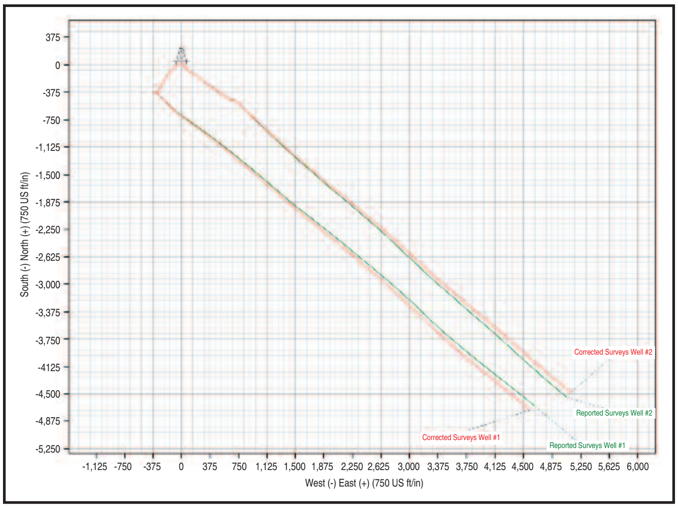

magnetic drill string interference or instrument bias and scale errors using IFR and MSA. After identifying and correcting the systematic errors, the corrected surveys were delivered to the rig site through the Web interface for directional steering.

A comparison of magnetic declination values computed from the Permian IFR model against the International Geomagnetic Reference Field (IGRF) model showed a root mean square (RMS) difference of 0.26 degrees and a maximum difference of 1.32 degrees. Comparing the Eagle Ford IFR and IGRF models showed an RMS difference of 0.14 degrees and a maximum difference of 0.50 degrees. Because declination is applied directly to magnetic azimuth when calculating directional surveys, the RMS positional error for an 11,000-foot lateral resulting from using the IGRF model would be 50 feet in the Permian and 27 feet in the Eagle Ford.

Bottom-hole locations for all 138 IFR/MSA-corrected well paths were compared with the bottom-hole locations of the original well paths computed from each wellbore's original MWD surveys. The RMS of the bottom-hole location horizontal positional change was 78 feet and the maximum horizontal positional change was 269 feet. Figure 2 summarizes these results.

**FIGURE 3A**

### Comparison of Corrected versus Reported Well Paths (Closer than Planned)




For wellbores that were analyzed after drilling, the difference in position represents how far the bottom-hole locations actually were placed, compared with the original measurements. For wellbores that were evaluated and corrected in real time (the case for the majority of wells), the difference in position represents the distance the bottom-hole location would have been from the plan without applying advanced survey management.

An important consideration to note is that changing wellbore position does not always occur in the same direction. Depending on the polarity of drill string magnetization, wellbore direction, and the direction of the magnetic declination error, the standard MWD-measured wellbore could be to the left or right of the actual position. This is especially concerning because it means that horizontal wellbores are very likely to converge and diverge,

**FIGURE 3B**

### Comparison of Corrected versus Reported Well Paths (Farther Apart than Planned)

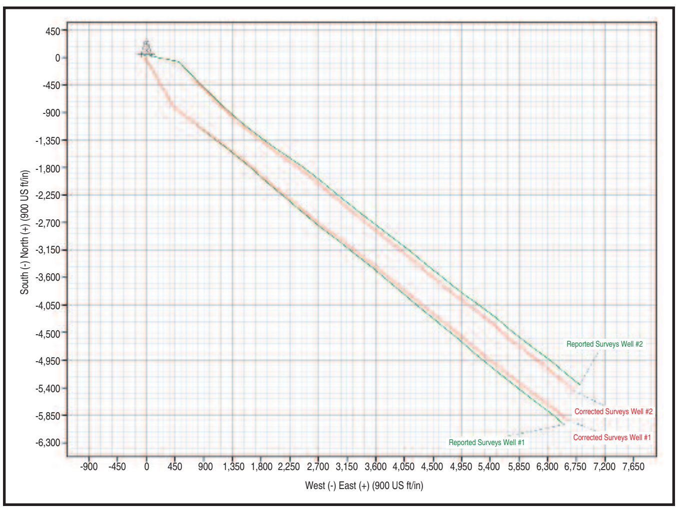
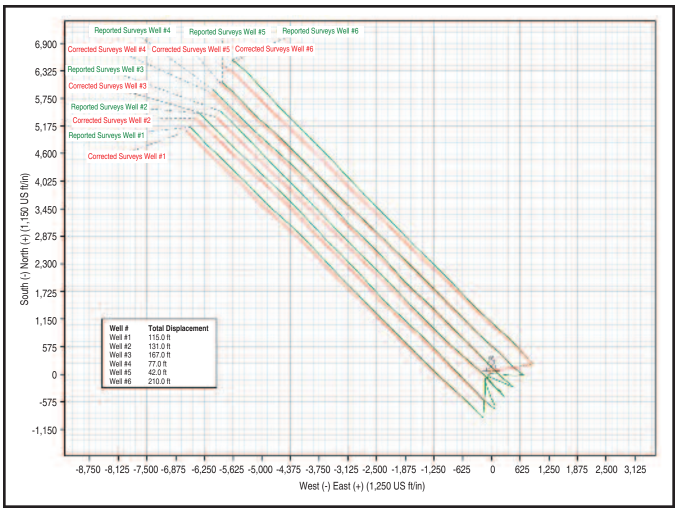



**FIGURE 4**

### Comparison of Corrected versus Reported Well Paths (Entire Well Pad)



which subsequently decreases and increases lateral spacing at the bottom-hole location.

**Example Wells**

Figure 3A shows two wells that would have approached closer than the planned spacing if advanced survey corrections had not been applied, while Figure 3B shows two wells that would have been drilled farther apart than planned if the MWD surveys were not corrected with IFR and MSA.

Figure 4 is an example of a multiwell pad that was analyzed in real time. It demonstrates how the wellbores could have been drilled (too close or too far apart from adjacent laterals) if real-time survey corrections had not been applied, and how inaccurate well placement can adversely impact spacing throughout a horizontal shale development. One also should consider how inaccurate well placement could impact future infill drilling. If enhanced recovery processes or new well completion techniques call for infill drilling, it is easy to see the challenge associated with placing wells in a field with inaccurately drilled wellbores.

As these examples illustrate, applying advanced survey corrections in real time reduces standard MWD error and ensures accurate wellbore placement to help minimize misinterpretations of well spacing test results. Improved well placement accuracy allows operators to drill horizontal shale wells as close to planned spacing as possible to effectively drain the entire reservoir area while avoiding over-capitalization from excessive drilling.

IFR and MSA represent the most cost-effective solution for correcting standard MWD surveying and substantially improving wellbore accuracy. IFR greatly improves the accuracy of geomagnetic reference declination, which can reduce positional uncertainty more than 30 percent. MSA is one of the most powerful forms of survey quality control, and is highly effective at identifying gross errors and reducing systematic errors. This can further reduce uncertainty, achieving total reductions by as much as 60 percent compared with standard MWD surveying.

A major advantage of the IFR/MSA method is that it can be applied in real time while drilling to enable wellbores to be steered using the most accurate surveys available. Placing wellbores accurately to begin with will have a positive impact on field development and increase the feasibility of future infill drilling programs. ❐

**Editor's Note:** ISCWSA is affiliated with the Society of Petroleum Engineers Wellbore Positioning Technical Section. For information on the ISCWSA error model and the OWSG anti-collision software tool codes, see http://www.iscwsa.net.


SHAWN DEVERSE

*Shawn DeVerse is co-founder of Surcon Ltd., a wholly owned subsidiary of Magnetic Variation Services LLC. He has a background in various drilling disciplines, including drilling fluids, managed pressure drilling, directional drilling and well planning. As president of MagVAR, he supports product development, technical sales, and operations management. DeVerse holds a B.S. in biosystems and mechanical engineering from the University of Arizona.*

STEFAN MAUS

*Stefan Maus is founder and director of Magnetic Variation Services LLC and a senior scientist at the University of Colorado. Formerly the geomagnetism team lead at the National Oceanic and Atmospheric Administration's national geophysical data center, he supervised the production of the World Magnetic Model and developed the first high-definition geomagnetic model. Maus holds a B.S. in mathematics and an M.S. in geophysics from the University of Munich, and a Ph.D. from the National Geophysical Research Institute in Hyderabad, India.*