THE AMERICAN OIL & GAS REPORTER®
APRIL 2018
The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Decision-Support Solution Improves Drilling Performance, Reduces Nonproductive Time

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HOUSTON–Operators are using advances in drilling technologies, techniques, instrumentation and data aggregation systems to significantly improve drilling rates and reduce nonproductive time. Drilling multiple horizontal wells from a single pad has enabled operators to benchmark drilling performance and make real-time adjustments to drilling parameters based on those benchmarks. But current systems may be delivering suboptimal drilling performance.

Today, the effectiveness of real-time adjustments to drilling parameters may be hindered by uncertain surface and downhole measurements and the inability of humans to aggregate multiple streams of data in real time. A recently introduced drilling optimization system addresses these issues by incorporating a Bayesian network into operators' drilling rig data aggregation systems. This Bayesian network-enhanced decision-support system updates a probabilistic model in real time to track variations in drilling conditions.

It identifies drilling dysfunctions by tracking the movement characteristics of various sensor data in relation to model-predicted values and aggregates this information to produce a holistic drilling optimization index.

This novel "cone drilling" system combines Bayesian network-based dysfunctions identification with mechanical specific energy (MSE) tracking to create a single normalized quantity upon which drillers can make decisions to adjust drilling parameters.

The cone drilling system automatically determines whether the drilling optimization index is below a specified threshold and provides recommended parameter changes to improve drilling performance. Suggestions may include changes to weight-on-bit (WOB) or rotary speed (rpm), or both. The system delivers these recommendations to the driller as a text or visually.

Drilling Cone

Visual representations of suggested actions are in the form of a cone-shaped figure projected on a WOB-rpm plot (Figure 1). The cone, with its dimensions and orientation calculated from dysfunction beliefs, indicates the action the driller should take–increase or decrease WOB or rpm–to mitigate the dysfunction. The system also may recommend that the driller engage or disengage automatic control systems.

Recommendations are plotted using current operating conditions as the apex of the cone. The shaded area within the cone is defined by operating parameters that will improve the drilling performance, or drilling optimization index. From this simple chart, drillers can quickly and easily determine necessary steps to enhance drilling efficiency. The cone also indicates to the driller the limits that each parameter of WOB and rpm may be moved in relation to the other.

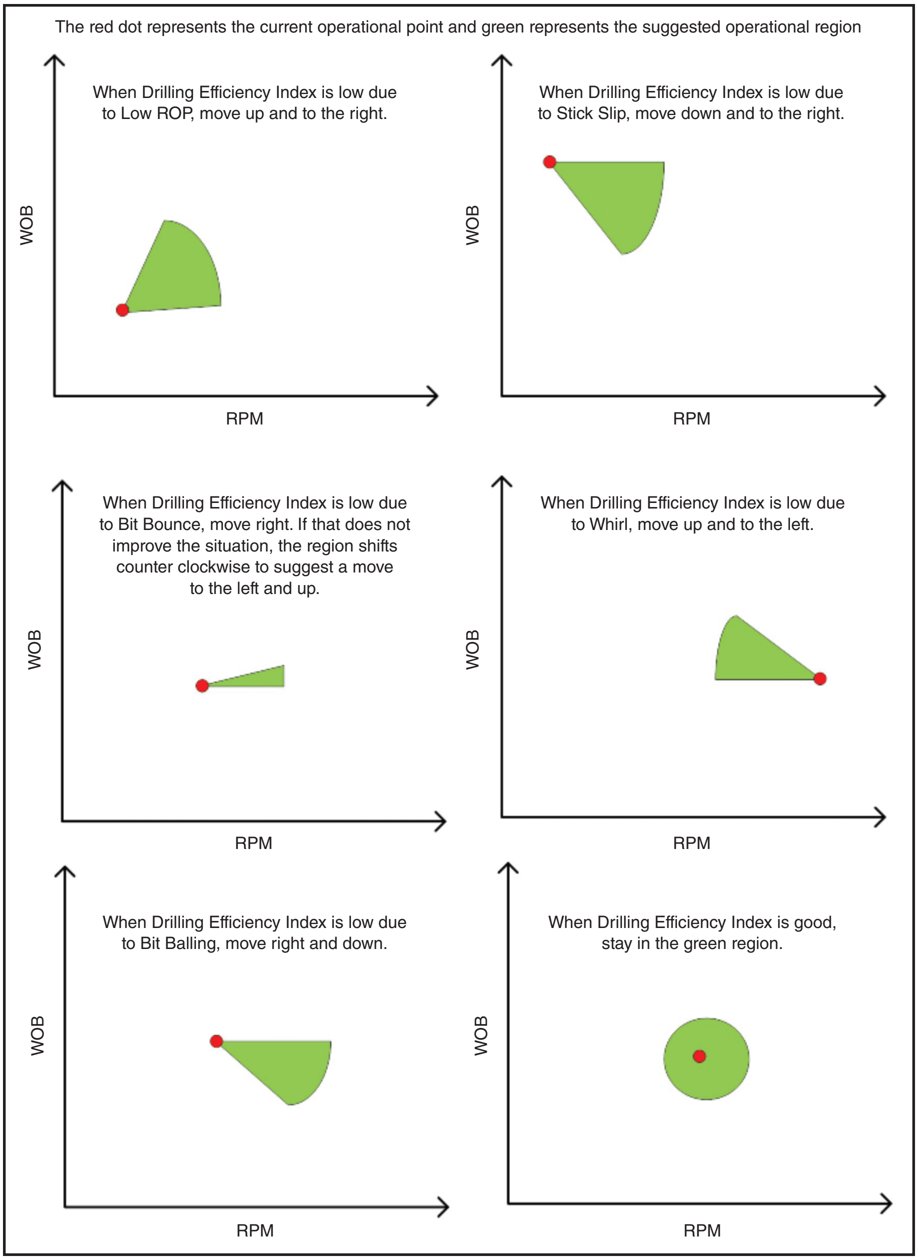
For example, when low ROP results in a low drilling optimization index, the cone shape and position on the chart tells the driller to move up and to the right on the curve (increasing both WOB and rpm) to establish drilling parameters that increase the drilling optimization index. The amount and direction that each of these drilling parameters can be moved is limited to the area of the cone to ensure that other dysfunctions are not created by move.

Similarly, when low efficiency results from a dysfunction identified by the system, a cone is generated that suggests corrective action corresponding to that dysfunction. When drilling inefficiency is caused by stick-slip, the shaded area of the cone will cover an area on the plot down and to the right of the apex, indicating a need to decrease WOB and increase rpm. The shaded area allows the driller to easily understand what values for each parameter potentially will eliminate the stick-slip condition.

The cones also can serve as a guide to the driller in the presence of other dys-

FIGURE 1

Visual Display of Suggested Actions (Cones)



functions. Bit bounce, for instance, is represented by a narrow cone that indicates the need for only a slight increase in WOB while increasing rpm. However, if the system determines a continuing drilling dysfunction after corrective action is taken, the cone shifts to recommend the driller move up and to the left, meaning decreasing rpm and increasing WOB.

Whirl produces a cone that is shaded up and to the left, which is a recommendation to increase WOB while decreasing rpm; a bit balling cone is essentially opposite to whirl and recommends the driller reduce WOB while increasing rpm. Depending on the area of drilling operation, the cone behavior can be adjusted using historical and field-based prior knowledge.

When the drilling index is at or near optimal, the figure appears as a single data point of current WOB-rpm parameters in or near the center of a shaded circle. This quickly makes it clear to the driller that parameters should be held constant.

Decision Support System

Cone drilling is the visual output of a decision support system that eliminates the uncertainty of drilling by using a probabilistic framework combining real-time surface measurements, derived quantities, such as MSE, bit aggressiveness and formation data. These parameters are encoded into a set of probabilistic features indicative of either the location of a particular physical attribute or of an attribute trend.

Location features include ROP, stick-slip alarm (SSA) and the ratio of MSE to the unconfined compressive strength of the rock. Movement features may be classified using linear curve-fitting performed over a moving window of attribute values. Features are used to infer the beliefs of various drilling dysfunctions and the belief of an optimal drilling condition. The result is to create a drilling optimization index that is calculated for every instant of time during which a drilling activity occurs.

The index considers the presence of various dysfunctions as well as suboptimal drilling rates. The Bayesian network easily compensates for missing data and allows for easy addition of other dysfunctions.

To aggregate trends from data collected by various sensors, the system workflow first reads real-time drilling parameters, synchronizes different reporting frequencies and preprocesses data to remove outliers, missing values and to summarize high-frequency data. If it detects, based on sensor data, that the rig activity is drilling, the system calculates MSE, bit aggressiveness and SSA magnitude from collected sensor readings.

A set of discrete probabilistic weights, or conditional probability tables, connect the network nodes. The drilling dysfunction node is assigned a prior probability distribution based on the expected frequency for each of the modeled dysfunctions of bit balling, bit bounce, stick-slip, whirl and a category of other dysfunctions, such as autodriller and downhole motor failure.

The posterior probability distribution of the drilling dysfunction node is updated at every instant that a drilling activity is recorded. The outcome of the drilling dysfunction node corresponding to no dysfunction detected yields the instantaneous value of the drilling optimization index. The probabilistic formulation naturally results in a drilling optimization index between 0 and 1, with 0 being inefficient and 1 being optimal drilling. When the index approaches 0, dysfunctions are defined and the system recommends actions to mitigate them. Because the system also displays variation of the index with depth, the driller is able to easily see how formation changes impact drilling performance (Figure 2).

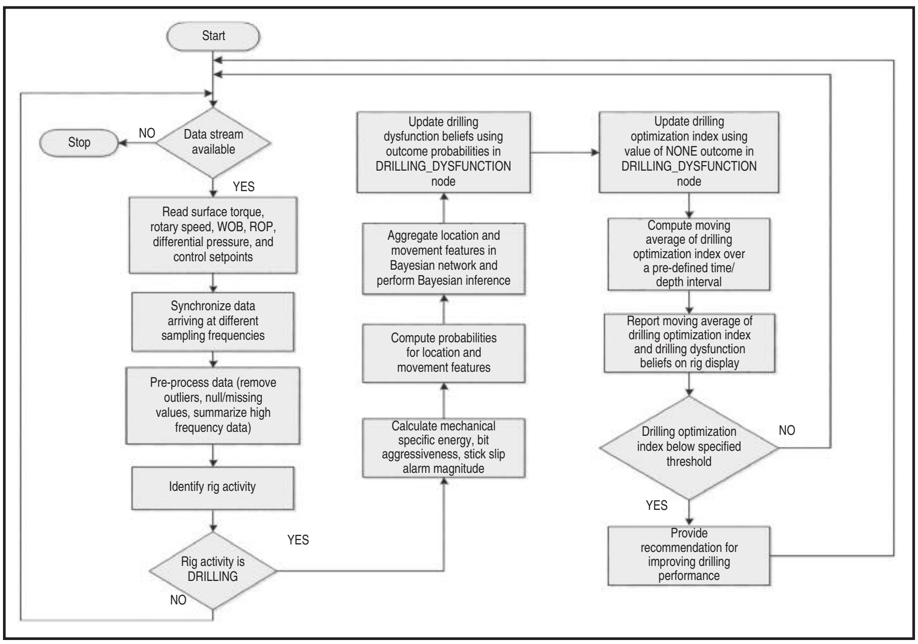
Optimization Index

Driller buy-in of automated decision-support systems is critical to their success, but is often overlooked by innovators. Because few drillers are familiar with such concepts as Bayesian networks and MSE, developers of the new methodology placed significant emphasis on human factors when implementing it. Besides including the easily understood cone drilling display, they designed the drilling optimization parameter to be displayed in an intuitive "speedometer-type" visual as a single, dimensionless index.

The index may be graphed on a depth-

FIGURE 2

Drilling Optimization Flow Chart



based chart and used to generate daily reports and to benchmark drilling parameters for various depths and geological formations. Contractors and operators may use this data to improve drillers' skills, set drilling benchmarks and prevent drill bit and mud motor failures.

In early 2017, Apache Corporation integrated the drilling optimization index into its real-time data aggregation and distribution software on 20 North American onshore rigs. The integration process was guided by human factor engineering principles. The drilling optimization index and drilling dysfunction beliefs have dedicated displays that include a color-coded dial with intuitive green (optimal drilling), orange (acceptable drilling with room for improvement) and red (inefficient drilling) to facilitate monitoring of drilling efficiency, and time-based and depth-based trend charts (Figure 3).

For a focused study, the operator applied the principles of the new system to six wells that were drilled from the same pad to ensure uniform comparisons. The drilling optimization index was calculated in the WOB-rpm space at a particular depth within the lateral hole section (Figure 4).

Four of the wells indicated that they were operating with high drilling optimization indexes. The other two wells, however, exhibited stick-slip at the same depth, causing their drilling optimization index to fall while their ROP values remained high. In two wells, ROP and WOB values were very close, but had very disparate drilling optimization values of 0.99 and 0.40, respectively. The wide range of these index values may have been caused by factors such as bit condition, wellbore tortuosity, hole cleaning or other downhole conditions.

The differences in outcomes for these six wells, at the same depth or in the same formation, illustrate that drilling parameters appropriate for one well in a pad are not necessarily appropriate for other wells drilled from the same pad.

Results And Conclusions

The developers of the technology also attempted to generate drilling optimization heat maps directly from the drilling data of the six wells by plotting the drilling optimization index in the WOB-rpm space over a range of depths within the same formations. They drew contour plots from the scattered operating points using linear interpolation. Corresponding ROP values and stick-slip and whirl beliefs were similarly plotted while other beliefs, such as bit-bounce, were deemed sufficiently low to be disregarded.

They concluded that because drilling parameter heat maps can be highly nonlinear and nonconvex, arriving at a global optimum may be difficult, or impossible, to achieve in practice. In addition, they found that drilling optimization heat maps generated from idealized models may be highly inaccurate when compared with actual drilling data.

The work described in this article focuses on a methodology to derive a drilling optimization index. This index and the

FIGURE 3

Display Showing Dial, Time-Cased Trend Chart and Cone

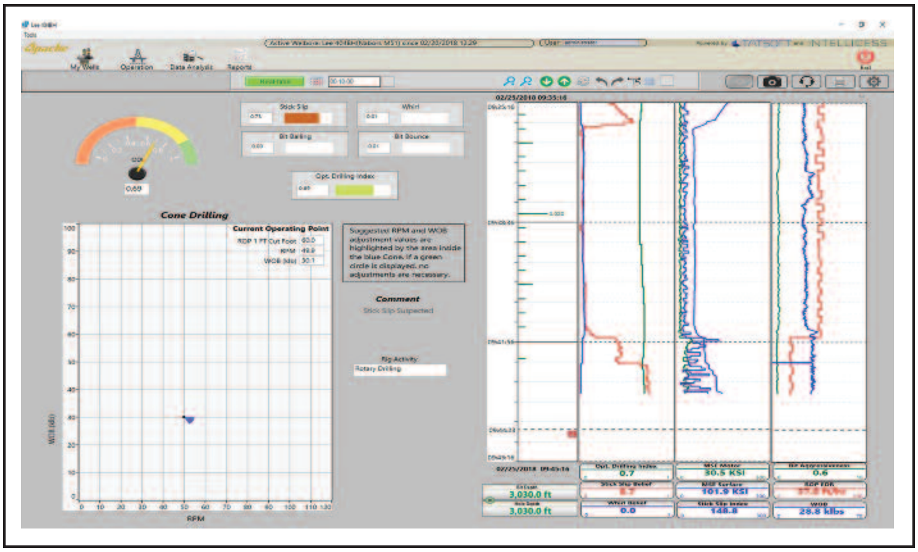
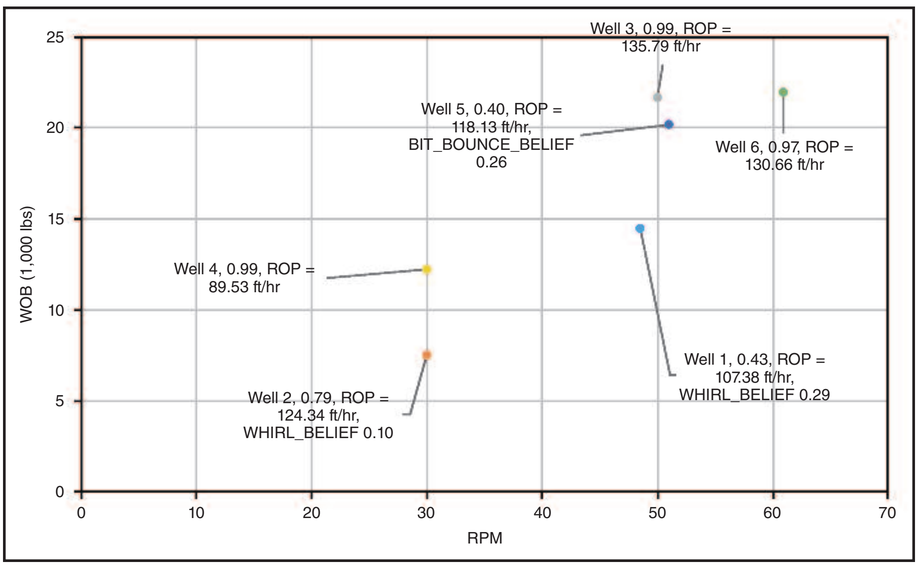


FIGURE 4

Drilling Optimization Index (at 11,550 feet)



dysfunction beliefs allow drilling software to calculate an operational cone that depicts optimal drilling parameter suggestions. A case study on the use of such cones for drilling optimization is being prepared.

One of conclusions drawn from this work is that when a holistic, normalized index automatically aggregates all drilling dysfunctions, the driller is freed from the task of monitoring trends. Drillers are then able to focus on determining optimal WOB and rpm operating points.

Because of large uncertainties that undermine the ability to accurately assess formation properties, hole geometry, wellbore tortuosity, bit conditions and other drilling conditions, the work demonstrates that optimal drilling regions within a WOB-rpm plot vary widely, even among wells drilled on the same pad. Therefore, it is difficult, if not impossible, to arrive at such regions through models.

The drilling optimization index and dysfunction belief values enable the driller to move toward a better solution, but global optimality is not guaranteed because drilling dynamics are highly nonlinear.

Determining drilling parameters through post-well analysis should be done with caution. Those parameters may serve as starting points only, but real-time data better reflect reality and provide pointers for better drilling parameters.

Operational cones can be calculated and provided to the driller in a visual format to help implement drilling parameters that attenuate dysfunctions and improve drilling efficiency. ❒

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