

Program Reduces NPT In Barnett Shale

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OKLAHOMA CITY—An operator must answer two primary questions to determine the necessity of drill string quality assurance initiatives: What is the probability of failure, and what would be the impact—financial or otherwise—of a failure event? For onshore operators, both the probability and impact of failure events have increased significantly as the industry has ramped up technically challenging horizontal drilling activity.

In the past, balancing the answers to these questions with the expense of additional quality management measures presented a challenge to onshore operators. However, the rapid growth in horizontal drilling makes it economical to implement a robust quality assurance program to reduce nonproductive time (NPT). Some of the drivers are:

- The increase in stress placed on drill string components while drilling horizontal wells;
- The increased cost of directional bottom-hole assemblies compared with vertical BHAs;
- Higher day rates and service costs; and
- The availability of suitable drill string components.

Devon Energy Corporation implemented an aggressive quality management program in its Barnett Shale operations to reduce risks and expenses resulting from drill string failures. Initially, the program addressed excessive NPT related

to normal weight and heavyweight drill pipe (HWDP) fatigue failures. These failures resulted in tube washouts and twist-offs, and created significant expenses associated with additional pipe trips, sidetracking and equipment losses.

The operator first established a base line for drill pipe failure-related NPT, and then tracked changes in NPT over two years as the quality program was developed and implemented for drill pipe inspection, machine shop and hard-banding processes. At the end of two years, NPT time related to drill pipe failures had been reduced by 47 percent, with negligible NPT in the final two quarters of the measurement period.

Analysis indicated a substantial net savings to the operator when comparing the decreased NPT with the investment in the quality program. In fact, the program resulted in an estimated annual net savings of \$1.5 million in rig costs alone.

Mud Motor, MWD Failures

Devon Energy also was experiencing significant NPT related to mud motor (MM) and measurement-while-drilling tool failures in its Forth Worth Basin operations. Encouraged by the results of the initial quality program focused on drill pipe fatigue failures and facing a large number of anticipated motor runs, the quality management plan was consequently expanded to include MMs and MWD tools.

The quality consulting company ensured that industry standards and vendor procedures were followed with respect to inspection, assembly and function testing MM and MWD equipment. Initial

quality audits of the operator's primary directional service providers allowed formal documentation of quality gaps and the development of individual quality plans for vendors. The program evolved to include an in-house project manager and multiple field technicians for third-party witnessing of the inspection, assembly and testing processes.

During the 13-month study from May 2008 to June 2009, NPT related to MM and MWD failures decreased by 79.5 percent and 61.6 percent, respectively. Furthermore, the drill pipe and HWDP quality program established in the initial study continued to yield positive results. Analysis indicates a significant net savings in operating cost, resulting in a 30.8 percent increase in average monthly footage drilled per rig.

Each type of tool presented unique challenges given the different failure modes experienced. MWD failure modes included fatigue cracks that resulted in washed out or parted rig-end and/or service connections, jammed or broken pulsers, malfunctioning batteries, and lost communications. MM failure modes included chunked stators, fatigue cracks that resulted in washed out or parted rig-end and/or service connections, internal connection back-offs, plugged motors, parted stator housing caused by fatigue crack propagation through housing walls, and broken bearing mandrels.

Although not defined as a failure, poor or weak performing MMs also reduced drilling productivity and contributed to issues in achieving proper build rates in the curve sections of horizontal wells. A review of these failures and performance



problems convinced Devon Energy that quality issues were driving NPT. To confirm this assumption and formally document quality conditions in each vendor facility, the quality program in place for drill string tubulars was expanded to include MM and MWD equipment.

Primary Work Scopes

Structurally, three primary work scopes defined the quality program: quality audits, third-party quality monitoring, and quality program management. Quality audits were used to evaluate and formally document each vendor's quality management system. This included reviewing:

- Personnel training and certifications;
- Inspection, assembly and function testing equipment condition and calibration practices;
- Tool repair, storage and handling practices;
- The availability of required standards at work locations, including Standard DS-1[®] and vendor standard operating procedures (SOPs);
- Thoroughness of vendors' SOPs, including inspection, assembly and function testing requirements; and
- Competency of both inspection and assembly personnel.

Nonconformances were documented, reported to the operator, and discussed with the vendor for correction. The severity of the nonconformance and the impact of the corrective action on the vendor's operations were considered in developing deadlines for compliance. For example, a nonconformance related to an expired calibration of a makeup/breakout torque unit could be remedied much faster than purchasing and installing a digital torque recorder.

After quality audits were conducted, third-party quality assurance technicians were deployed at the shop level to:

- Enforce process-sensitive procedures according to the required standards defined by the operator;
- Ensure that acceptance criteria were defined and applied according to vendor SOPs and/or operator requirements;
- Ensure that tools were prepared and sent to the rig according to specifications (for example, the correct degree bend was set on a motor adjustable housing);
- Witness and record function test results;

• Provide guidance on specific tool attributes outside the defined acceptance criteria, but still "fit for purpose;"

- Record and communicate inspection results, including accepted, rejected and repaired equipment;
- Educate inexperienced vendor personnel in inspection procedures and acceptance criteria with daily guidance and on-the-job training;
- Close nonconformances found during quality audits; and
- Identify and document new non-conformance reports during daily observations.

Although the audit function was critical in formally documenting initial quality gaps, on-site involvement of quality assurance field technicians was crucial to ensuring that day-to-day practices were consistent and showed continuous improvement.

Devon Energy expected to run approximately 2,000 motor assemblies in 2008. This volume dictated the need for a dedicated resource to manage the execution and coordination of the office and field-level activities. The role of the quality program manager included:

- Attending operations meetings to stay current on drilling activities and address issues in real time;
- Establishing and communicating inspection and assembly call-out procedures to all operator superintendents and vendors;
- Coordinating additional vendor and service company shop audits to identify additional tool and service providers;
- Implementing quality control programs developed for other operator divisions by the company and communicate lessons learned with respect to MMs and MWD tools;
- Coordinating equipment inspections and quality assurance technicians when required by the operator;
- Supervising field quality assurance technicians and communicating all relevant information required by the operator;
- Transmitting daily updates, inspection reports and damage photo logs to relevant operator personnel; and
- Working with vendors and service companies to improve the overall quality of the infrastructure.

Initial Steps

Tools that performed poorly or failed were returned to the vendor for tear-down

and analysis. Working with the vendor, T H Hill conducted failure investigations to formally document all procedures during the tear-down process, identify the root cause of each failure event, communicate findings to the quality program manager and operator, and recommend a solution to mitigate or reduce the occurrence of similar failures in the future.

The initial audits formally documented a "snapshot" view of quality practices at the vendor shop level and gave guidance for implementing the quality program. Specifically, MWD tool and MM inspection, assembly and function testing were witnessed and evaluated during routine tool qualification. These shop audits documented critical procedures and requirements that either were omitted or applied incorrectly, and demonstrated to the operator that third-party quality management for directional tools was necessary.

The shop-level quality audits uncovered quality gaps during inspection, assembly and function testing for both MM and MWD tools. The audits initially focused on mud motor providers, which were often part of the same vendors' MWD divisions. In such cases, audit findings from one facility impacted the quality improvement program for both tool types.

Mud Motor Quality Findings

For mud motors, general shop discrepancies included the fact that some shops were not ISO 9001-2000 certified, often because of the newness of the locations. Personnel training was not always complete or properly recorded since a large percentage of shop personnel were newly hired.

In other cases, internal audits were not performed or scheduled, third-party vendors were not audited before selection, and quality managers were not in place to oversee quality measures. Specific to the handling practices, thread protectors were not used while transporting components from one work location to another (increasing the risk of damage to already inspected connections), and open-ended thread protectors were used on connections during transport (allowing trash and debris to enter the motor).

Documented MM inspection issues included not having proper gauges at work stations to perform required measurements to rig-end or internal connections, and pit gauges used to measure damage indications were missing from work sta-



tions. In other instances, equipment to perform wet or dry magnetic particle inspections for connections and tool body outside diameters was not present.

Ultraviolet meters, burma-castrol strips, or centrifuge tubes either were not available or were not used to verify UV light intensity, magnetic field orientation and strength, or wet magnetic particle solution concentration, respectively. When verified, wet magnetic particle solution concentration was found to be out of the acceptable range. Other issues included not referencing inspection standards during procedures, failing to reinspect repaired connections after returning from the machine shop, and incomplete inspection documentation

During assembly, components that were marked as rejected for repair or scrap were later approved for use. Rotor/stator interference was not typically measured, even though it was required in the vendor's SOP and by the customer. In some cases, stator condition was not verified prior to power section assembly using a bore scope. Signs of premature rubber chunking were not identified. Applying threadlocking compounds was overlooked on required connections, and rotors were mishandled during makeup in the torque machines, resulting in damaged/raised chrome. This damage can lead to premature stator chunking.

In other instances, measuring device calibrations either were expired or were not clearly marked, and components marked as damaged were found on "ready racks" or assembled to bearing sections. In addition, stator storage practices compromised the integrity of an accepted stator (some were found outside in the elements with no thread protectors or covering to protect the stator rubber), and rotors were stored on steel racks, although the vendors' SOPs required storing rotors with no metal-to-metal contact.

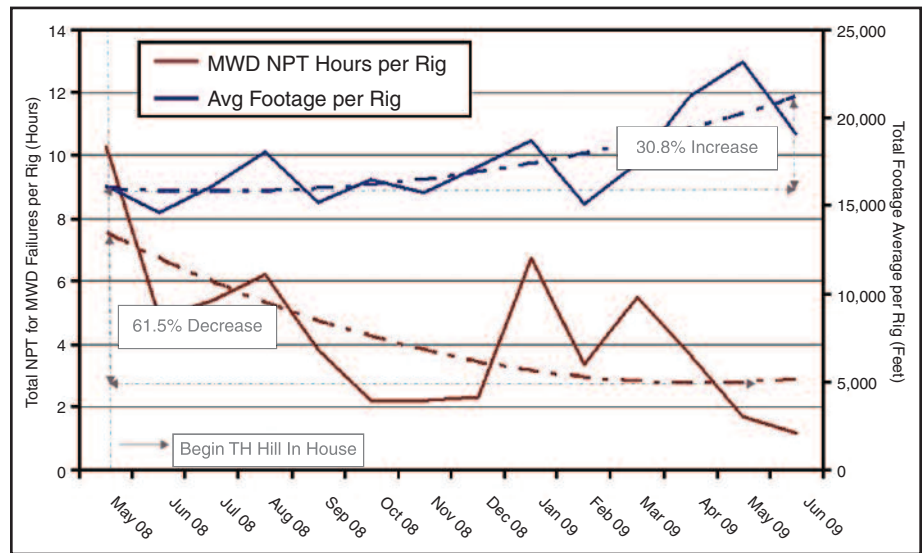
In function testing, equipment to perform MM flow loop tests either was not present or was not functional.

MWD Tool Quality Findings

In regard to general shop discrepancies for MWD tools, it was found that tools were thrown on top of MWD components during tool load out, sometimes damaging exposed MWD components.

Dye liquid penetrant inspection test blocks were damaged or missing at workstations. These test blocks are used to verify that the dye penetrant and developer for inspecting nonmagnetic components

FIGURE 1
Monthly MWD NPT and Average Footage Drilled



work properly at a given ambient temperature and dwell time. In other cases, inspection documentation was incomplete and/or inspection standards were not found at workstations.

During MWD tool assembly, shop measuring devices were out of calibration, and air was not removed from the tool assembly per the vendors' SOPs (it was requested that a vacuum unit be employed to remove air after assembly).

While function testing assembled MWD tools, tests were performed to individual components in the lab or shop, but were not tested as a complete system. In addition, performance tests did not account for hole conditions.

Impact Analysis

Although Devon Energy realized a significant decrease in NPT after implementing the quality program, understanding the operational impact of the decrease was key to determining the program's success. Building on the data collection process from the first case study, the operator and quality consulting company gathered data from field reports and the operator's drilling software database. Incidents of NPT attributed to MM and MWD tool failures were isolated to quantify the results of the initiative. The data were normalized and two matrices were developed that included each rig's hours of NPT per month and average footage

FIGURE 2
Monthly Mud Motor NPT and Average Footage Drilled

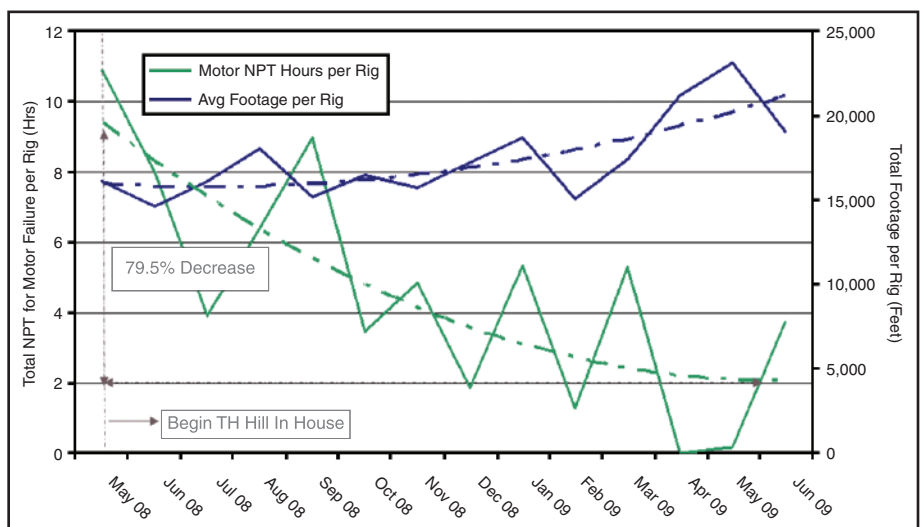
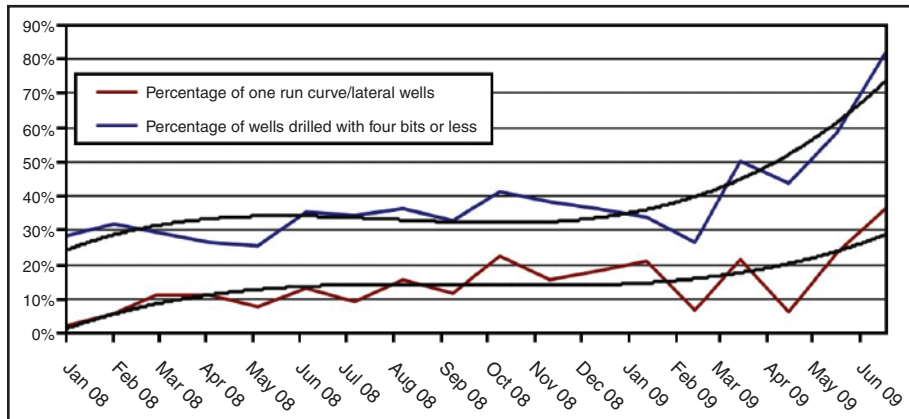




FIGURE 3
Percentage of Wells Drilled with Four or Fewer Bits



drilled per month.

Figure 1 shows the average number of hours of MWD tool NPT each month per rig from May 2008 to June 2009, as well as the average monthly footage drilled per rig. Over the course of the study, MWD tool NPT declined 61.5 percent, from 7.8 hours to 3.0 hours per rig each month. Likewise, average monthly footage drilled per rig increased by 30.8 percent, from 15,200 to 22,000 feet.

Similarly, Figure 2 shows the average number of hours of MM NPT each month per rig, as well as the average monthly footage drilled per rig over the same period. Mud motor NPT declined 79.5 percent, from 9.5 hours to 2.0 hours a month per rig.

The expanded program produced immediate and measurable results. The reduced NPT from MM and MWD tool failures allowed the operator to drill wells more efficiently and spend less time retrieving malfunctioning or broken down-hole tools.

In addition, better performing MMs and more reliable MWD tools allowed the operator to drill wells with fewer bits. Figure 3 contains a data set of 749 wells. The bottom curve represents 100 wells that were drilled with three bits, using only one bit in the curve and the lateral. At the time of the study, wells drilled with one bit through the build section and lateral had increased to 30 percent.

However, it was not uncommon for Devon Energy to elect to use four bits if offset data showed historical issues in the build section, or if a longer lateral section was required to reach total depth. The top curve in Figure 3 represents all wells that were drilled with four or fewer bits. Over the course of the study, the percentage of

wells requiring four or fewer bits increased from 24 to 72 percent.

Initial Program Update

The original quarterly tubular NPT cost versus the rigs covered in the quality program was updated to reflect the continued success of the initial drill pipe quality program. Figure 4 plots NPT cost over the course of the implementation process. When a full-time project manager was engaged to oversee quality across the entire rig fleet in the second quarter of 2007, a drastic reduction in NPT from drill pipe and HWDP fatigue failures was realized. The NPT experienced in 2008 for drill pipe and HWDP fatigue failures remained negligible, confirming the success of the operator’s approach.

The primary directional vendors were eager to improve the quality of their processes, and ultimately, the performance

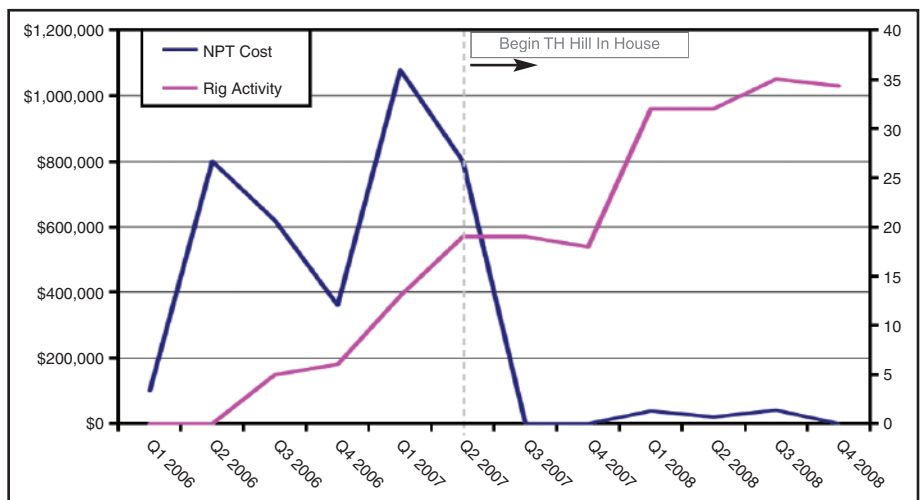
of their tools. By working with the operator and quality consulting company, the vendors eliminated documented nonconformances and revised procedures to improve inspection and assembly processes. Likewise, through cooperative failure investigations between the vendors and quality consulting company, the root causes of failures were identified and addressed to mitigate the risk of future failures.

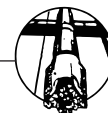
One example is recommending that full-body dry magnetic particle inspections be performed to detect any fatigue cracks or other defects present in the stator tube as specified in Standard DS-1. Full-body inspection had not been required for stator housing in the vendors’ SOPs. The operator had been finding cracks and holes in the stator housing tube during drilling operations, and failures were reduced after implementing this additional procedure.

In another example, the operator had experienced several failures related to chunking stators. Analysis of these failures showed that the torque units’ die marks were damaging the rotor chrome approximately 10 inches from the end. The makeup practices were revised and the stator failure rate was decreased.

Devon also had experienced several failures caused by broken bearing mandrels. It was determined that the mandrels were breaking because of fatigue cracks initiating from midwall defects that were undetectable using surface magnetic particle inspection. The operator requested that an ultrasonic inspection be performed on the bearing mandrels to detect mid-wall defects before a fatigue failure could

FIGURE 4
Updated Quarterly NPT Cost versus Rigs Covered By Quality Program





occur. Since initiating this recommendation, only one mandrel has failed.

Motor plugging was also an issue. In fact, three motors had become plugged within a span of two days. The quality consultant company was asked to witness the MM teardowns and responded to the operator with a documented root cause report. It was found that as part of its lost circulation control program, drillers frequently would bypass shale shakers and carry lost circulation material in the mud. Devon was able to quickly address the problem and revise its procedures to eliminate this type of failure.

Program Recommendations

As horizontal drilling becomes more common onshore, the cost of nonproductive time from directional tool assemblies can reach unacceptable levels. Comprehensive quality initiatives can reduce NPT significantly and generate positive financial impacts. A well managed quality program can yield additional benefits for operations beyond reduced NPT.

Based on the results of Devon's program in the Barnett Shale, recommendations for implementing a similar aggressive approach for reducing NPT in onshore drilling operations include:

- Using operational data to determine the drivers of failure-related NPT by tool

type;

- Limiting the scope of a quality program in the initial stages to focus on high-impact and/or high-probability types of failures;

- Performing an initial assessment to provide a base line for quality conditions in the regional infrastructure;

- Developing appropriate metrics to evaluate progress and refine the program;

- Aggressively incorporating field-level quality assurance;

- Working cooperatively with vendors to minimize the business impact of new quality initiatives where possible; and

- Appointing a full-time program manager to coordinate and execute a program for high-cost and multirig drilling programs. □

Editor's Note: Information on the original quality management program to reduce drill pipe-related NPT can be referenced in SPE/IADC 119383, a technical paper presented at the 2009 Society of Petroleum Engineers/International Association of Drilling Contractors Drilling Conference & Exhibition in Amsterdam. Additional details on the expanded program to include mud motors and MWD tools is available in SPE/IADC 140305, presented at the 2011 SPE/IADC Drilling Conference & Exhibition in Amsterdam.

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