

# Overcoming Drilling Performance Limiters for Extended Horizontal Wells in the Permian Basin

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## Abstract

The Permian Basin of West Texas and Eastern New Mexico has been a prolific production region, currently representing about 45% of the total tight oil production in United States. Horizontal drilling from multi-well pads and hydraulic fracturing techniques have improved over the past decade leading to an increase in production and improved well economics.

The area is typically divided into two main basins; the Midland Basin and the Delaware Basin. The most commonly targeted formations are the Spraberry, Wolfcamp & Bone Spring formations. A significant number of technical challenges are faced while drilling the production zone, including curves varying from 10°/100ft to 14°/100ft, followed by an average lateral horizontal section length of 10,000ft through shale-limestone formation facies, where downhole dynamics, tool failures, poor hole quality, wellbore positioning and drillability problems have caused inconsistent performance and impacted the operator’s strategy to efficiently develop this basin.

A systematic approach was utilized to define opportunities for improvement, analyze and implement strategies that enable the capture of technical lessons and re-engineering solutions for the main performance limiters including: bottom hole assembly (BHA) design, active management of drilling parameter and effective directional drilling practices.

As a result, continuous improvement of drilling operations has been realized, reducing the total time to drill a well by about 20% while increasing the number of wells drilled per quarter; delivering longer runs, smoother and more efficient wells, enabling operators to successfully extend horizontal production sections to lengths exceeding 12,000 feet.

## Introduction

The Permian Basin of West Texas and Eastern New Mexico is approximately 250 miles wide and 300 mile long and covers about 86, 000 square miles in 52 counties. It is divided into three sub-basins: Midland Basin, Central Platform and Delaware Basin with the Midland and Delaware basins accounting for the vast majority of the oil and gas development in the region (see Figure 1).

The Midland Basin is on the eastern side of the Central

Basin Platform (uplift). The formations targeted for horizontal drilling in the Midland Basin are the Spraberry and Wolfcamp formations. These formations consisting of mostly gray shales with interbedded limestones and some sandstones were deposited in the Permian period and were formed by a thick subaqueous deltaic system and later covered with floodplains.

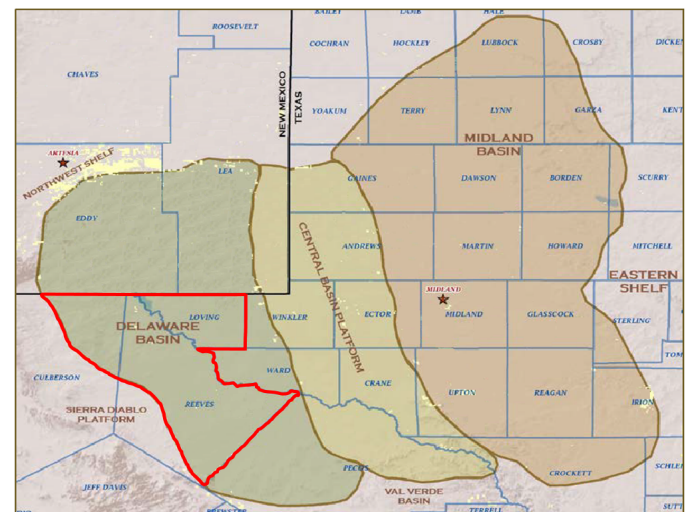


Figure 1. Permian Basin. (Source: www.shaleexperts.com)

The focus area for this paper is the Delaware Basin with wells located in West Texas nearing the New Mexico border in the counties of Reeves, Loving and Culberson, Texas.

Located on the western side of the Central Basin Platform, target formations for horizontal drilling in the Delaware Basin include the Bone Spring and the Wolfcamp formations. These formations are characterized by dark gray shales with occasional limestone nodules and interbedded sandstone deposited in deep marine waters of a rapidly subsiding basin. This structure of thin carbonate and sandstone beds characterized by a basin floor carbonate structure leads to a highly randomized occurrence of these carbonate facies (Hoak, T. DOE/PC/91008-7). This feature has caused the greatest challenge when drilling production sections within the Bone Spring and Wolfcamp formations. The Delaware Basin subsided at a faster rate than Midland Basin therefore similar target formations are encounter at deeper true vertical depth (TVD). (Figure 2).

Tight oil production requires consistent cost-efficient solutions to develop the resources in the Permian Basin. Factory and pad drilling are the current and future development strategies in the area, bringing forth their own set of challenges such as aggressive well profiles and increasing horizontal displacement.

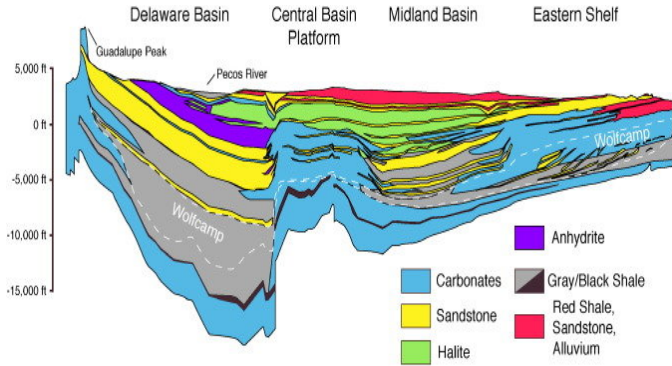


Figure 2. Permian Basin Cross-section. Source: <https://www.researchgate.net>

**Systematic Approach**

The systematic approach concept is commonly defined as “methodical approach repeatable and learnable through a step-by-step procedure”. This standard methodology has been used in the oil industry as part of the “continuous improvement cycle” to implement adjustments of different variables to improve performance (see Figure 3).

The standard process compares the desired goals and the current performance, then performance limiters are defined and analyzed to define “opportunities for improvement” where “systematical” solutions will be provided for each limiter. Next is measuring the impact to the operation and then testing the next improvement as part of a system.

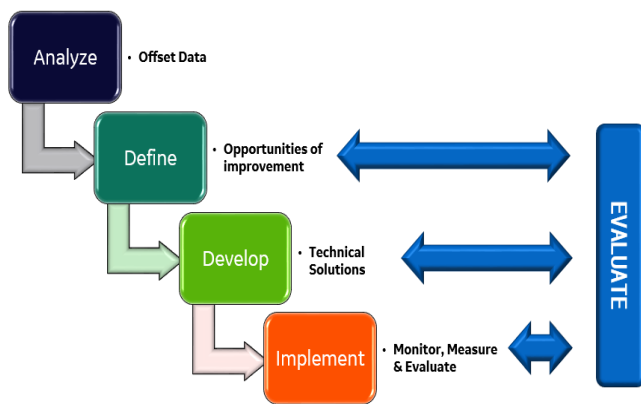


Figure 3. Systematic Approach

**Defining Performance Limiters**

Operators in the Permian basin are constantly looking for strategies to improve performance in the drilling phase. During the last down-turn cycles several studies and analyses were performed to implement efficiencies in downstream

operations to minimize the time from spud to production.

A typical well design used in the area is shown (see Figure 4). The majority of programs include a three string casing design. The 17½-in surface hole section is commonly drilled vertically to isolate ground water aquifers at ~2,000ft TVD; followed by a 12¼-in intermediate hole section with a majority of this section drilled vertically. Some directional work usually takes place to define the well’s horizontal displacement within the lease, and casing is usually set to cover as much of the Bone Spring formation as practical due to fluid losses experienced in this section. Finally there is the 8½-in production hole section that kicks-off the curve and efficiently lands in the target formation to drill the horizontal well through the production section.

3 STRING WELL DESIGN	SECTION	HOLE	CASING	MD	TVD	INC
	Conductor	26"	20"	140'	140'	0°
	Surface	17.5"	13.375"	2,500'	2,250'	0°
	Intermediate	12.25"	9.625"	9,950'	9,940'	0°
	Curve (KOP)			10,000'	9,990'	0°
	Curve (LP)	8.5"	5.5"	10,900'	10,500'	90°
	Lateral			21,000'	10,500'	90°

Figure 4. Permian basin, 3 strings generalized well design.

During the last years several analyses have been published with the aim of improving drilling performance in the surface and intermediate sections through the Delaware Mountain Group (DMG). These analyses have mostly focused on minimizing drilling problems such as directional control in the vertical section, poor penetration rates and accelerated wear on drillstring components, by using downhole sensors to define and implement best drilling practices. (Hood, et al. SPE/IADC-173170-MS) – (Bailey, et al. IADC/SPE-163503-MS)

Meanwhile drilling the production hole is considered the most challenging operation and the section with the most room for improvement, taking about 70% of total well drilling time and requiring drilling efficiencies to save time and money. After analyzing several wells in the area a holistic analysis was performed to define the main drilling performance limiters. A series of challenges including wellbore trajectory, BHA design and operational practices were highlighted as opportunities for improvement.

Bent motor assemblies have long been preferred for directional drilling in the Permian basin due to the harsh drilling environments and need for multiple bit trips for any given sections. The industry has been incentivized to expand the

Continuous Proportional Steering Rotary Steerable Systems (RSS) operations in the Permian Basin, based on this technology's proven success to improve performance and efficiently extend the lateral lengths across many unconventional basins in North America (Livingston, D. et al. IADC/SPE-178875-MS).

The curve and the lateral sections of the production hole have very different challenges. For the purpose of this analysis the curve and lateral sections have been evaluated separately to isolate the main performance limiters as understanding the dysfunctions experienced while drilling each area.

### Drilling the Curve

Commonly a function of the intermediate casing depth, lease shape and of the field development plan, the curve section is designed to drill in 2D or 3D at high dogleg severities (see Figure 5), to obtain a rate of curvature ranging from  $10^\circ$  to  $14^\circ/100'$ . A very flexible bottom hole assembly (BHA) design is required to land the well in the desired formation when the vertical depth (TVD) from casing shoe to landing point is limited. This flexible assembly will bend along the curve allowing the continuous proportional steering RSS to yield the required DLS. The strong hardness contrasts of the highly differentiated interbedded formation directly affect the BHA yield and the directional response, compromising the landing point and generating variable reactive torque and downhole dysfunctions that affect the bit structure and electronics life, leading to performance failures.

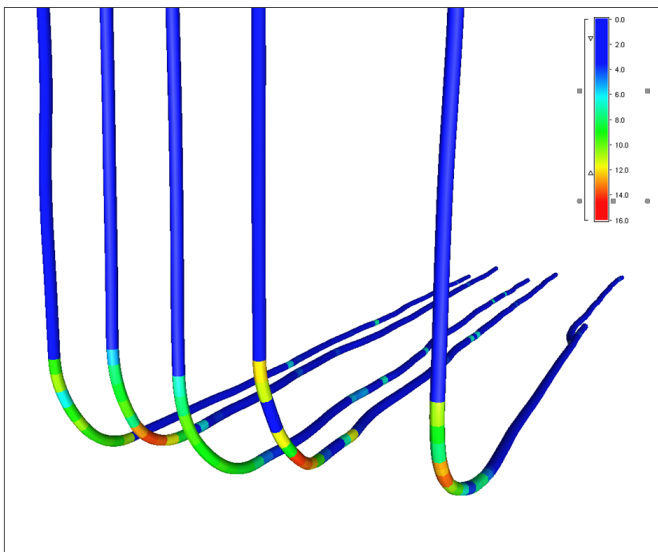


Figure 5. Curve Section colored by Dogleg Severity (DLS)

### Drilling the Lateral

When the well is landed the BHA dynamics and bending forces change. The BHA is still in compression but the assembly is now placed in the lower part of the borehole, affected by the gravity in addition to the energy imposed from the applied drilling parameters. The combination of axial load

represented by Weight on Bit (WOB), the hydraulic energy by flowrate and torsional energy generated by the drillstring revolutions from surface and motor revolutions from fluid flow are expected to deliver an efficient rate of penetration (ROP), but also generate some dynamic dysfunctions while drilling the horizontal section (Bailey, et al. IADC/SPE-163503-MS).

Wellbore positioning for long extended laterals is another common challenge, where vertical and horizontal drilling windows of varying dimensions are included in the well plan to ensure the wellbore is in the target formation, to constrain the well within the lease and to ensure the wells are optimally spaced for hydraulic fracturing and subsequent production success. Frequently the expectation for unconventional reservoirs is to drill horizontally through "one homogeneous formation"; however, the geology of the unconventional reservoir in the Permian Basin is characteristically "non-homogeneous" and contains large and unpredictable carbonate features within the shale packages (Hoak, T. et al DOE/PC/91008-7). These features are generally represented by negative drilling breaks along with strong trajectory deflections on the azimuthal and inclination plane, along with strong downhole dynamic dysfunctions affecting the overall performance for extended laterals where the objectives are reliability and time reduction.

As discussed before, the lateral distance is a function of the lease and the field development plan, and the current standard horizontal well is around 10,000ft (see Figure 6). These longer laterals, required to increase reservoir exposure, also pose new challenges in terms of torque and drag responses, hole cleaning capability, and the requirement to ensure maximum formation exposure that will require some level of reservoir navigation monitoring.

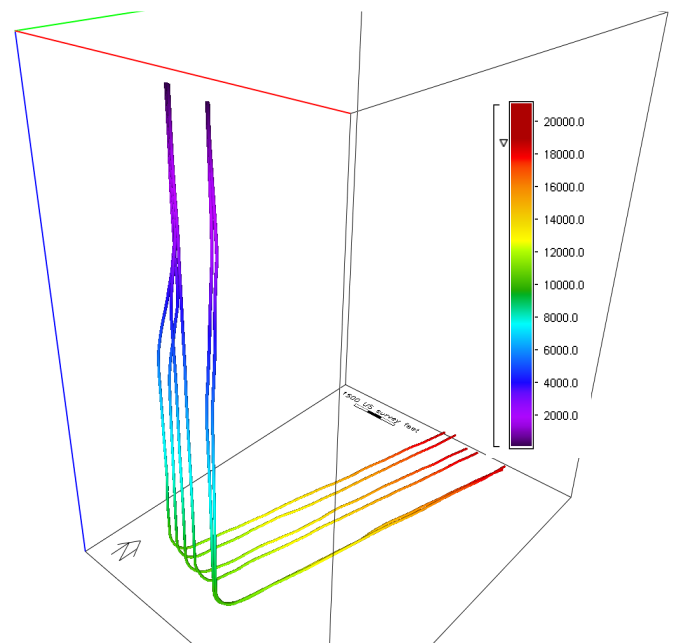


Figure 6. Well trajectory, colored by Measure Depth MD.



achieve the best balance of performance and reliability.

The first approach was to constrain all drilling parameters to better define the “Application Technical Limit. Although numerous parameters can be defined in drilling operations attention was focused primarily on three: WOB, bit speed (surface revolutions + motor revolutions), and differential pressure (pressure increase from off-bottom versus on-bottom drilling pressure). After constraining these predefined parameters and ensuring all operations were operating within the specified limits the result was a dramatic increase in tool reliability.

After an effective baseline parameter set was established and confirmed with measured reliability improvements, all parameters were revisited and challenged in a systematic manner. Two main outputs were evaluated while testing increasing in drilling parameters, as follow:

1. Drilling Performance: How did the variation of this parameter affect ROP, steerability and reliability?
2. Reliability: Did this variation cause any downhole dysfunctions in terms of vibrations or directional control?

Only one variable was evaluated at the time to isolate outputs and compare results. Drilling real-time measurements from surface & downhole sensors were constantly monitored to determine the effectiveness on varying each parameter.

During the post-job evaluation, high-density post-run memory data was analyzed to determine if any dysfunctions were occurring that may have not been transmitted to surface. A detailed physical inspection to downhole components also took place to determine if any physical tool damage had occurred. If the data review did not indicate any increase in dysfunction and the physical inspection did not point to accelerated tool damage, the revised parameter was opened to several other wells on a trial basis.

Only after numerous test with efficient and reliable results, would a new baseline for the “Application Technical Limit” be updated. Typically at least ten runs were required to prove a concept, where very limited or no dysfunction were observed.

### **Best drilling Practices**

Many operational problems that affect the overall drilling efficiency and accelerated wear on drillstring components have been tied to new personnel joining operations in the Permian Basin. The constant flow of personnel with little-to-no oilfield experience and personnel with experience outside the Permian Basin have made capturing and sharing lessons learned and updating best drilling practices curtail in conveying this local drilling knowledge attained over the past decade.

Local procedures have been adjusted using the regional field experience captured during this process to combine a tailored motor-assisted RSS BHA operating procedure and application specific technical limits. These two tools were used as main base for the local lessons learned repository with the main intention of efficiently evaluating and capturing the Best Drilling Practices that lead to minimized dysfunctions and ensure the overall performance.

To enhance the learning curve and address these

drilling practices, real-time surface, and downhole dynamics and mechanics information was transmitted, analyzed and evaluated, delivering immediate feedback and recommendations to improve wellbore operations.

A series of drilling practices related to on-bottom and off-bottom operations, proper connections practices, surveys, vibration mitigation while drilling and reaming, hole cleaning, torque and drag and many other drilling operations have been captured and shared with the field personnel as part of the continuous improvement cycle. This has been one of the lynchpins in bridging the knowledge gap present new personnel in the Permian Basin.

Operational and engineering teams have been appointed to proactively communicate best practices and ensure adherence thorough the field personnel team. This team is assisting in training new field operators on the implementation of these practices, as well continuing to capture, re-define and communicate lessons learned.

### **Results**

As a result of the implementation of this systematic approach process, a clear improvement on overall drilling performance has been realized. Utilizing a “fit-for-purpose” BHA to drill the curve and lateral sections, actively managing the drilling parameters to find the best balance of performance and tool capability, and providing the tools for the field personnel to rapidly understand the local drilling nuances and employ best drilling practices have all led to a dramatic increase in performance. Operators in the area have seen about 60% improvement in time required to deliver the HDLS curve section from an average of 33 hours to a current standard of about 13 hours. (See Figure 9). A steady reduction in drilling hours and reliably drilling the extended horizontal section has significantly reduced the total time to drill this section (See Figure 10). Although much of the focus of this project was dedicated to the production section many of the “Best Drilling Practices” carried over into the surface and intermediate hole sections. While there have been slight improvements in these sections many operators have resisted making the dramatic BHA and parameter changes in what has and still is typically a conventional motor BHA section.

These results combined with continuously pushing performance in the area has reduced total well delivery times by more than 10 days, representing a reduction of about 40% in drilling time (See Figure 11). While ensuring longer runs and consistent performance, well-to-well delivery has increased and now the number of wells drilled per quarter has subsequently increased. Now the ever-present push to extend the current technical limits brings forth new challenges. The wellbore quality deliver by the continuous proportional steering RSS proved to drill a high-quality wellbore while placing the wells in the desired productive zone, successful managing hole cleaning and torque challenges typical of extended laterals, enabling the operators to successfully plan and execute horizontal section exceeding 12,000ft.

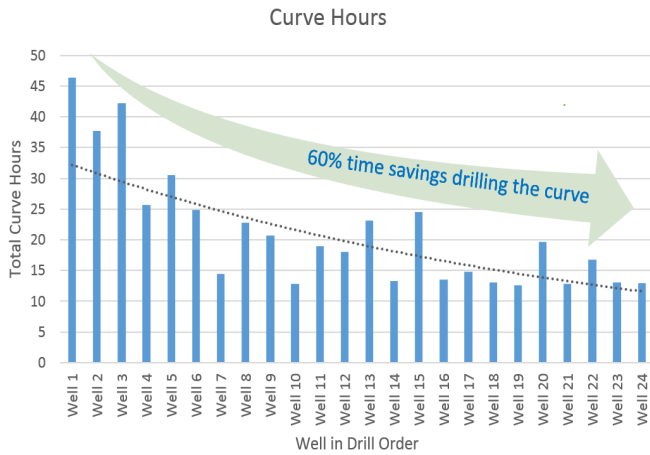


Figure 9. Drilling Hours to Drill High Dogleg Severity Curve Section

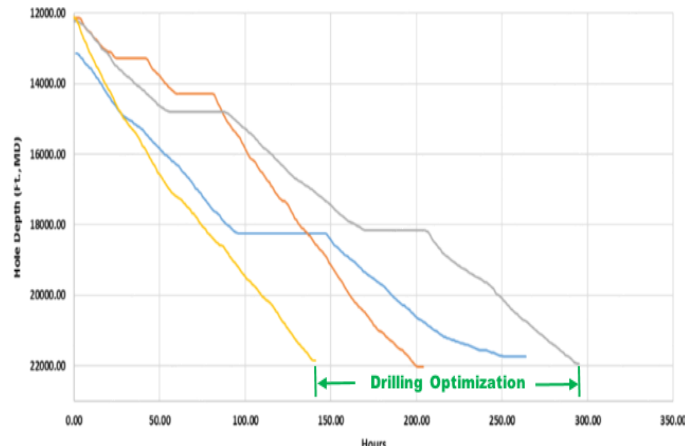


Figure 10. Total Hours to Drill Lateral Section

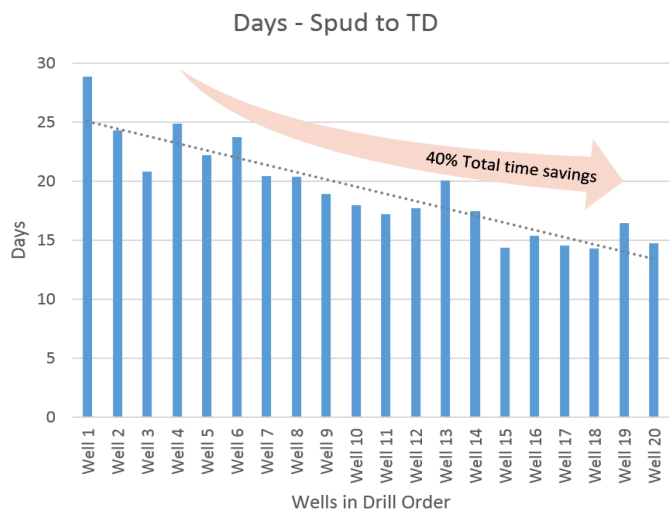


Figure 11. Drilling Performance Improvement for Complete Well

**Conclusions**

This process has proactively standardized operations with operators, drilling contractors and directional service providers. To implement these defined adjustments, all parties must be aligned. Standardization proved to be crucial to monitor performance and define success levels. This systematic approach to performance improvement is not unique to the oilfield; it is however to very challenging to align all parties when the definitions of success vary among stakeholders. This rapid uptick in activity in the Permian Basin allowed a unique setting to rein in all aspects involved in the drilling operations, and due to the quick pace and high volume of drilling operations many variables could be tested with almost immediate feedback.

High levels of record keeping and data management must be employed to provide useful analysis. While many wells were drilled over this time period not all were comparable. It is important to categorize wells based on specifics that may affect performance to ensure the variables are being analyzed on a like-for-like basis. Well profiles, target formations, bit selection, motor speed, mud properties, and a host of other variables should all be tracked in the data set to help identify appropriate offset wells to be included.

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**Nomenclature**

- BHA: Bottom hole assembly
- BUR: Build-up rate
- DLS : Dogleg severity
- DMG: Delaware Mountain Group
- FEA : Finite Element Analysis
- KPI : Key performance indicator
- MD : Measured depth
- NB : Near bit
- NAR: North America Region
- NM : Non-magnetic
- PDC : Polycrystalline Diamond Compact
- RNS : Reservoir navigation service
- RPM: Revolutions per minute
- RSS : Rotary steerable system
- ROP : Rate of penetration
- TD : Total depth
- TVD: Total vertical depth
- VS : Vertical section
- WOB: Weight on bit
- 2D : Two dimensional
- 3D : Three dimensional

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