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Reducing Wells Cost by Increasing Drilling Efficiency

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Abstract

Significant improvements have been achieved in well operations by focusing on integrating drilling engineering, well planning, logistic coordination, and task execution. This paper discusses a six-step approach to increase drilling efficiencies, resulting in reducing drilling time and well costs by more than 20 percent.

These six steps are as follows:

1. Generate an accurate well AFE
2. Use a systematic multi-phase approach to well design and execution incorporating investigative techniques, modeling and drilling engineering analysis, to generate a well plan and apply lessons learned to well operations
3. Use a database to provide benchmarking data for measuring efficiency of task execution and identify potential problems on offset wells for further study and review
4. Use a rig based program to break multiple drilling steps (wireline logging, running casing strings, nippling up BOPs or picking up new BHAs) into component tasks and compared this data to historical benchmarks to reduce flat spot time
5. Use a software program with real-time drilling parameters to calculate the optimum weight on bit, pump pressure and rotary speed to maximize penetration rate and provide event recognition for trouble avoidance
6. Provide logistics coordination to eliminate waiting on materials

Evidence presented by three case studies in the Gulf of Mexico and West Africa show a broad based benefit can be created when successful drilling practices are linked with efficiency tools.

Introduction

The industry concurs that a better business process is needed to deliver more efficient well execution in both exploration and development projects.[1] Industry well design teams recognize that approximately 70 percent of the deficiencies in the execution process are due to the lack of project definition and planning rather than poor operations.[2]

An integral and vital part of the economic analysis of an oil or gas property is the correct estimation of drilling costs. Wells that are drilled above the estimated AFE jeopardize this economic analysis and complicate exploration and development decisions. Due to its importance, the drilling team should devote the necessary time and effort to formulate a basis for a reliable drilling forecast and achieve these results during well execution.

Poorly planned wells usually result from insufficient time spent uncovering and analyzing offset, seismic, and structure data. This leads to an ineffective well plan and drilling program. Life cycle and field evaluation with the exploration or development team of geologist, geophysicists, reservoir, drilling and production engineers, facilities, and financial personnel, requires that everyone has validated each segment of the well design to insure the final well bore profile is consistent with the minimum production and economic requirements.

Combining good drilling engineering, including detailed investigative techniques with efficiency tools, will result in a cost effective execution. Use of efficiency tools during the execution phase allow the operation team to focus on critical path management, enhance rate of penetration, and recognize events for trouble avoidance.

Well AFE Preparation

The drilling engineer normally is requested by management to estimate anticipated well costs in an exploration or development area. Time constraints often do not allow the engineer sufficient time to review various offset wells prior to submitting a cost estimate. The drilling engineer's value to his company is greatly enhanced if he is able to provide a cost estimate with a high degree of reliability.

Unrealistic drilling cost estimates undermine the efforts of the exploration and development team by reducing the number of wells drilled during a budget cycle. The success or failure of many projects can be traced to the quality of the original cost estimate. The engineer should be given adequate time to study the offset and area wells in detail, along with the associated geology, to generate a geologic and offset model to prepare a preliminary well program. This pre-well program will provide the foundation to accurately estimate the well cost.

Planning Engineering

Careful planning and evaluation is required to successfully complete a project whether drilling easy normal pressure wells or difficult wells that have a combination of abnormal pressure, salt, rafted shale, high angle or other objective drilling difficulties. A systematic approach that can be repeated from well to well regardless of the difficulty will result in efficient well programs. Drilling practices vary from well to well depending on the geology, well depth and potential hole problems, but a multi-phase systematic approach with drilling engineering, well execution and final well audit, separated into phases, will provide for a successful well operation.

The first phase incorporates investigative techniques, modeling and drilling engineering analysis to generate a well plan. During the engineering phase a methodical step by step process insures that all aspects of the well and well offsets are analyzed. An example of what the first phase can include is as follows:

- Life, field cycle and G & G review, including design and operating philosophy – this important step validates the economics of the project with a proposed total depth hole size and insures the well bore design is compatible with the completion and production scenarios. Some wells are drilled today without a clear picture of how the well will be completed and tied-back into an existing infrastructure. Performing a life cycle study increases the likelihood of compatible drilling, completion and production designs. Requesting all parties to sign off on the life cycle document places responsibility for decisions with specific team members.
- Offset well information review and analysis – offset wells typically have many clues of problems associated with a specific area. Reviewing these wells and generating a detailed stick diagram allows the engineer to gain an overview of the area resulting in the most efficient well design. Marking up logs with well information and generating a list of lessons learned from each offset well, allows the engineer to assimilate information from all of the area wells.
- Pore pressure / fracture gradient / overburden gradient, shallow water flow (if necessary), and shallow gas analysis – accurate prediction of pore pressure and fracture gradients is an essential item in successful well execution. Pore pressure determination allows the engineer to properly forecast the well's pore pressure profile generating a proactive approach to planning mud weights, casing sizes and setting depths. An accurate knowledge of formation pore pressure is a key ingredient for an efficient, safe and economic drilling program. There are many different methods to evaluate pore pressure.[3] A method we have found successful is a technique based on well log data. Using Geopressure Estimation Software (GPES), sonic data from wireline logs can be used to construct a pore pressure model for the proposed area.[4] GPES allows the engineer to create a computer generated compaction trend based on regression analysis, therefore minimizing an interpreter's bias. Using GPES, pore pressure data can be inputted much quicker and without errors rather than performing the evaluation manually. For rank wildcat wells, where sonic data is not available, seismic interval velocities can be used over the well bore and/or well path. This data can be entered into GPES to obtain an associated pore pressure curve. Seismic interval velocities should always be requested when purchasing 3D data. This data in normally provided without additional cost when 3D data is acquired. Typically, geologists do not perform pore pressure evaluation and they have no need for interval velocity data, therefore this data is often not requested. Many seismic companies charge for this data if requested after the initial 3D data is purchased.
- Directional scenarios – this evaluation includes torque and drag modeling, surface location verification and directional plan. Optimization of the directional program will result in a more efficient well plan. Reviewing directional plans with the exploration team allows the engineer to optimize the directional program in conjunction with casing setting depths and also meet the geological objectives of the well.
- Casing point selection and design – once pore pressure evaluation and directional scenarios have been concluded, casing points can be selected. Optimizing the casing setting depths is a combination of the directional program, pore pressure transition zones, hole mechanics and

rig capability. Each item has an impact on well success and all need to be considered to create the optimum well design.

- Drilling fluid and solids control – selecting the most compatible drilling fluid to insure good hole cleaning and chemically stabilizing the hole provides for a successful well program.
- Industry best practices review and lessons learned – this part of the evaluation provides an external perspective to an organization and allows for combining many good practices used within the industry from a wide range of wells drilled. Lessons learned vary from well design practices, to casing and hole design, to operational procedures. These lessons are essentially a compilation of the most successful practices and practices to avoid in the area in which the well is to be drilled. This is vital in producing a successful well program.
- Drilling rig analysis and third party equipment analysis – a successful drilling program will result from maximizing the efficiencies of the contracted drilling unit through effective implementation of an optimized and well-planned drilling program. In complex wells with multiple strings of heavy casing, evaluating the drilling rig constraints provides the opportunity to generate contingency plans to increase the efficiency of casing setting operations.
- Vendor technical capabilities and performance review – this insures the right vendor is selected for the specific well type and water depth. Documenting vendor track records provides a constructive framework in awarding future work.

The second phase of the project is the implementation of the drilling program. In this phase lessons learned from the study of offset wells and industry best practices can be applied. Efficiency and well interpretation tools, described below, should be integrated into well operations. Drilling cost and problems can be significantly reduced by the early recognition of pore pressure transition zones. Evaluating pore pressure in the planning stage allows the well to be designed correctly but still does not reduce the dependence on field evaluation of transition zones. A pre-spud meeting, which can be performed both onshore and offshore, insures all personnel associated with the project are briefed on the well design and program. This allows personnel to “buy-in” to all aspects of the well design and become familiar with the efficiency tools and processes.

After completion of well operations, the third phase of the systematic approach includes the well audit to identify areas of success and areas for improvement. A detailed well summary should be generated with corresponding lost time events per hole section drilled. This analysis will also include a discussion about the impact of good and bad decisions. This sets up the process so lessons learned on the well just drilled can be applied to remaining or future well programs. Drilling personnel sometimes are so busy preparing for the next well that this phase is often deleted. Deleting this step breaks the information chain and allows a re-occurrence of mistakes in future wells.

Well Database

Well Tracking System (WTS) is a database that drilling engineers can use to statistically benchmark critical path activities to provide flat spot and drilling time data necessary for well cost estimation. An example of a WTS format for summary of flat spot times is shown in Figure 1. This storage of flat spot data for different well complexities and types assists the engineer to input the “correct” estimation of time into the cost estimate. Inputting offset wells into the database allows the engineer to quickly compute the lost time factor for each well section and enables the engineer to focus on specific areas where an offset well had problems, Figure 2. Rotating hours can be listed either per hole section, Figure 3, or provided in a conventional bit record format. The database allows the engineer to break down well activities incrementally. Many engineers have data to support conductor, surface and intermediate casing flat spot times. These flat spot times usually combine too many operational activities to verify if lost time exist. Breaking down the flat spots into incremental steps and evaluating each step, during well operations, allows the engineer the opportunity to reduce the critical path activity time on the next well.

Operation Efficiency Program

Improved Drilling Efficiency and Accountability System (IDEAS™), provides a documented system for managing the critical path of individual and concurrent operations executed aboard the drilling unit though the use of programmed operations forecasts, performance benchmarks, and continuous feedback. This system can be used on any type of drilling unit and can be activated for single and multi-well programs. IDEAS helps to reduce flat spot time, reduce accident frequency, and make sure the “right” tool is in the “right” place at the “right” time. Activities are broken down into critical path and “other activities.” These “other activities” can be performed outside the critical path, reducing the traditional flat spot time. An example of reducing 11.3 hours of non-critical time from a diverter installation is shown in Figure 4. This type of time saving methodology can be performed on each flat spot.

Computer Program Enhances Well Operations

The Drill-Smart system (NDSS™) provides a continuous analysis of drilling parameters to optimize the rate of penetration. Through real-time data and information display in the rig office and on the rig floor, the Drill-Graph system allows advanced "event recognition", improved driller efficiency and trouble avoidance resulting in enhanced downhole risk management and improved drilling performance. A typical Drill-Graph and Drill-Smart screen are shown in Figure 5 and 6. The program graphically presents a "scan" of the well bore using real-time data (rotary speed, WOB, pump pressure, torque, bit position, pump strokes, gas, flow rate, bit weight, pit volume, trip tank, and annulus pressure), Figure 7. Any combination of data can be presented on the Drill-Graph screen. This allows the driller to identify bit floundering or bit bounce, fault cuts, sand caps, formation changes or drilling breaks as they occur, to identify problems and eliminate trouble time. Instantaneous D-exponent can be calculated to allow lower mud weights to be used, which reduces the incidence of differential sticking and facilitates casing setting depths.

The system utilizes the output of conventional, electronic rig sensors to populate a data matrix of sufficient size to represent a statistically valid sample of the current drilling condition, thereby improving upon current, manual methods of calculating the optimum weight on bit in at least three important respects. First, by automating the data gathering process, data points are much more closely spaced in time, capturing the response of the rate of penetration to even the minor variation in the weight on bit. Second, automation decreases the degree of random, human error introduced by visual interpolation of gauge readings. Third, utilization of current generation microprocessors allows essentially continuous updating the relevant calculations and optimization is preserved, even in the case of thinly bedded or heterogeneous formation. Although numerous investigations have revealed the effect of other parameters such as rotary speed or hydraulics on the rate of penetration, in the majority of instances, weight on bit exerts a primary influence on rate of penetration, and more importantly, is under the most direct control of the driller. For this reason, the computer algorithm is based upon the relationship between weight on bit and instantaneous rate of penetration. Once the bit is placed on bottom and a designated weight on bit is applied, the processor searches the matrix for the maximum value of penetration rate to determine the corresponding weight on bit. This bit weight is then set as the driller's target, and the target weight on bit and predicted rate of penetration are graphically displayed for the driller to act upon. A comparison of drilling the same formations with and without Drill-Smart is shown in Figure 8 and 9. Drilling without Drill-Smart, the driller applies an inconsistent weight on bit, often referred as "banana drilling", overloading and underloading the bit. Drilling with Drill-Smart, an optimum, consistent weight on bit is applied, increasing the instantaneous rate of penetration. The system is self-adjusting with regard to other drilling parameters such as rotary speed or level of hydraulic energy, and adjusts quickly to changes in formation properties that influence the drillability of the formation under the bit. Adherence to the target weight on bits increases the efficiency by 15 to 20 percent, resulting in lower rotating hours and cost savings, shown graphically in Figure 10.

One of the benefits of the drill-off computer algorithm is the ability to review the drilling response without shutting down the real time bit weight optimization system. This archive and browser function gathers all recorded drilling parameters in a database at a frequency of one data line per second. The browser function is then capable of reading this database either in real or historical time. This allows the drilling supervisor to switch to other screen parameters to assist in pore pressure interpretation or trouble avoidance. Figure 11 and 12 shows a screen indicating a drillstring washout and mud motor failure and subsequent twist-off. A drilling supervisor monitoring these screens could quickly identify events and stop drilling operations, avoiding such lost time as twists-offs, etc. Other event trends, such increasing over pull on connections or hole ballooning can be identified by the drilling personnel to prevent costly lost time.

The Drill-Graph data can be sent real time from the rig to shorebased operations office, via the Internet, to enable support personnel to "see" what is occurring at the well site. Better decisions can be made if all parties have access to real time data, that are not confused or diluted by verbal transmission of events.

Logistics Coordination

Insuring materials and equipment are ordered on a timely basis and selecting vendors and service companies who have the ability to supply goods and services promptly are vitally important to successful operations. Awarding contracts to vendors based on criteria of expertise and current workload insures work will be performed as planned and not subject to manpower or equipment shortage delays.

Loading supply boats at the shorebase with the equipment located for ease of offloading and placing critical items on top or beside other equipment insures critical path items can be offloaded first. Bulk supplies should be place forward of other equipment to prevent damaging containers and materials with seawater. During international operations where supply interruptions exist, loading all equipment and supplies for multi-well programs in the US and sea freighting equipment insures materials will be on location as the need arise.

Case Studies – Gulf of Mexico: West Delta and Grand Isle; and West Coast of Africa

Three wells have been selected, two in the Gulf of Mexico and one offshore West Africa. Following a disciplined approach resulted in a successful operation completing the wells in less than the technical limit or ideal time curve.

Case Study – West Delta

This relatively simple well drilled in West Delta Block 60, shows the effects of efficiently setting casing strings and maximizing the rate of penetration. Figures 13 and 14 show the Days vs. Depth curve and bit record graph, respectively. Notice that hole was being made in each 24-hour period for the conductor and surface casing point flat spots when logging and casing running operations occurred. This evidences the advantages of I.D.E.A.S.™ with the rig crew maximizing their efficiency and only performing tasks necessary to complete critical events. Time lost to unproductive operations was minimal at 9.1 percent. Actual days were 22.1 percent lower than estimated and 16.5 percent below the technical limit curve. Total rotary hours were reduced by 15.4 percent by using Drill-Smart to maximize the rate of penetration.

Case Study 2 – Grand Isle

This well, drilled in Grand Isle Block 106 with a TD of 19,100’, was a difficult well with complex pore pressure interpretation, 7,000’ of salt, and a sub-salt unstable basal shear zone. This well evidences the effect of disciplined pre-planning, predictive pore pressure evaluation, efficiently setting casing strings through difficult pore pressure transitions, salt and rubble zones, rate of penetration efficiency, and logistics scheduling for multiple strings of casing and equipment. In one of the wells studied that was drilled previous to this well, large discrepancies between actual pore pressure and mud hydrostatic were observed. This can occur for two reasons. First, the effective stress principle governing the relationship between pore pressure and fracture gradient ensures that overestimation of pore pressure causes overestimation of formation strength. This produces a false sense of security about the magnitude of mud weight. Second, the mud program design for a well is usually based on pore pressure estimates plus a trip margin and safety factor. The reality of a drilling plan based on overestimated pressures is that it puts unnecessarily inflated mud weights close to the real fracture gradient that will be encountered in the well. The offset well’s mud weights were increased in response to “gas units” detected by mud loggers and these “gas units” were interpreted as an increase in pore pressure. The conclusion was that offset wells had misinterpreted the pore pressure and the high gas readings were from gassy gumbo not increasing pore pressure. This allowed downsizing the casing program with a lower mud weight schedule and during well operations the rate of penetration was controlled to reduce the gas effect of the gumbo.

Salt was estimated in this well from 6,500’ to 14,000’ with an anticipated rubble zone of 500’ to 1,000’. The fastest offset sub salt in the area had previously taken 96 days to drill and evaluate. Figure 15 and 16 show the Days vs. Depth curve and bit record graph respectively. The well was drilled five days less than the technical limit or ideal curve. Actual days were 30.7 percent lower than estimated. Total rotary hours were reduced by 53.7 percent. Estimated savings using NDSS™ for enhancing rate of penetration and trouble avoidance was $21,000 per day.

Case 3 Study – Offshore West Africa

A group of five wells were drilled offshore Nigeria in OPL-230. The first well demonstrates the effects of disciplined pre-planning, efficiently setting casing strings, rate of penetration efficiency and logistics coordination for casing and equipment. An inventory of equipment and tangibles was not available in country, therefore all equipment was purchased in the US and ocean freighted to Nigeria. Figure 17 and 18 show the Days vs. Depth curve and bit record graph respectively. Actual days were 22.4 percent lower than estimated. Total rotary hours were reduced by 13.7 percent.

Conclusions

Moving from “average” to “successful” drilling practices can significantly impact the economics of a project. Using a disciplined approach to well design and execution results in successful well operations. Combining offset data, lessons learned, and engineering methods coupled with efficiency tools will enable the engineering and operations team to improve on offset well times. A successful operation is not a matter of finding a breakthrough type improvement. It is usually a grouping of small engineering and operating methods that, when combined, produce step changes in well performance. This combination has to be performed on each individual well or these improvements are quickly lost and well execution performance will be impacted.

Acknowledgments

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References

1. Clay, T., Hatch, A., “A New Well Design and Construction Process,” SPE Paper No. 57561, presented at the 1999 SPE Middle East DrillingTechnology Conference, Abu Dhabi, UAE, 8-10 November.
2. Schreuder, J., Sharpe P., “Drilling the Limit – A Key to Reduce Well Costs,” SPE Paper No. 57258, presented at the 1999 SPE Asia Pacific Improved Oil Recovery Conference, Kuala Lumpur, 25-26 October.
3. Draou, A., Osisanya, S., “New Methods for Estimating of Formation Pressures and Fractures Gradients from Well Logs,” SPE Paper No. 63263, presented at the 200 SPE Annual Technical Conference, Dallas, Texas, October 1-4.
4. Proehl, T., Onyia, E., Herkommer, M., “Assessing the Productivity Enhancement and Economic Impact of Geopressure Evaluation Computer Software,” SPE Paper No. 24447, presented at the 1992 SPE Petroleum Computer Conference, Houston, Texas, July 19-22.
5. Proehl, T., “Pore Pressure, Fracture Gradients, and Drilling Economics,” SPE Paper No. 27493, presented at the 1994 SPE/IADC Drilling Conference, Houston, Texas, February 15-18.

Figure 1. WTS - Flat Spot Summary Report

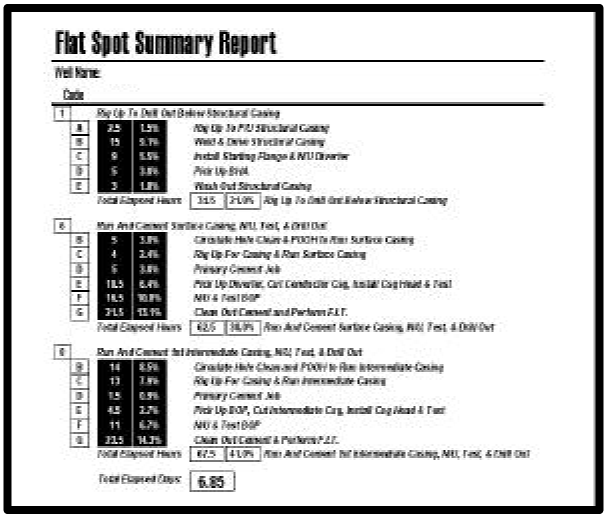


Figure 2. WTS - Lost Time Summary Report

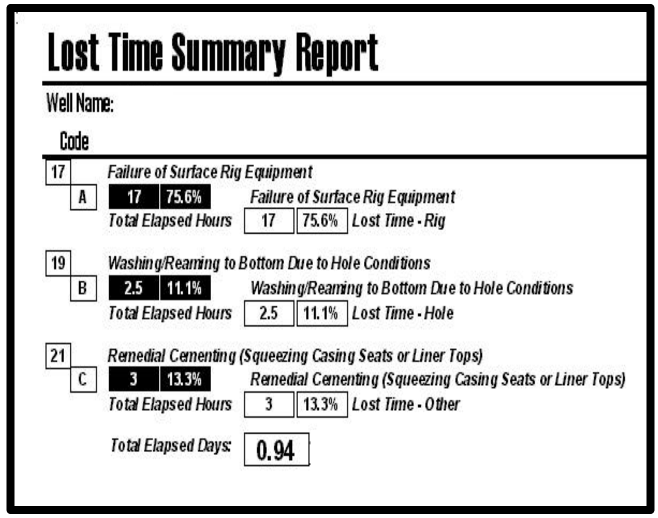


Figure 3. WTS - Rotating Time Summary

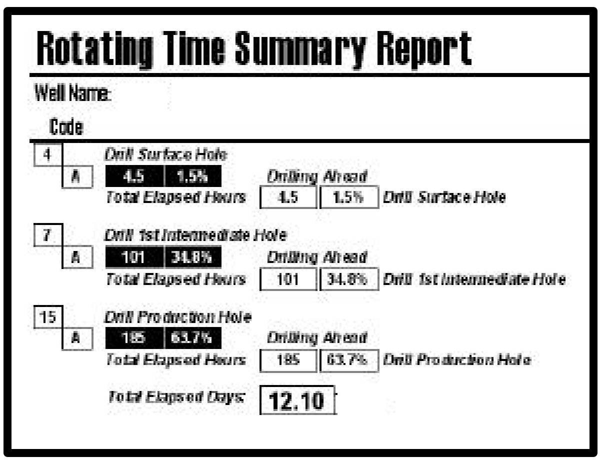


Figure 4. IDEAS program flat spot reduction

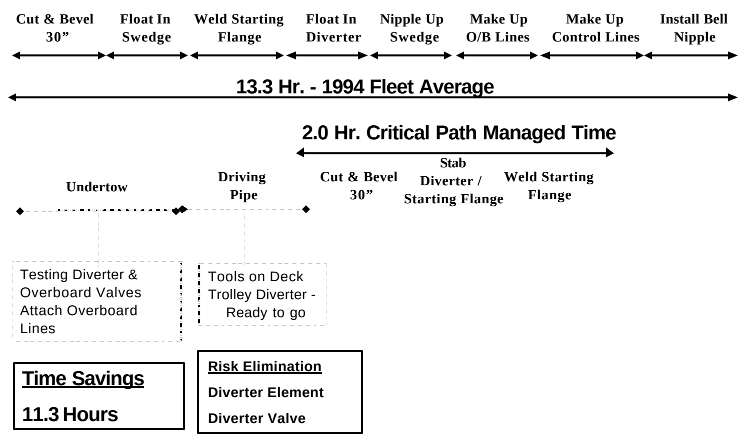


Figure 5. Drill-Graph screen

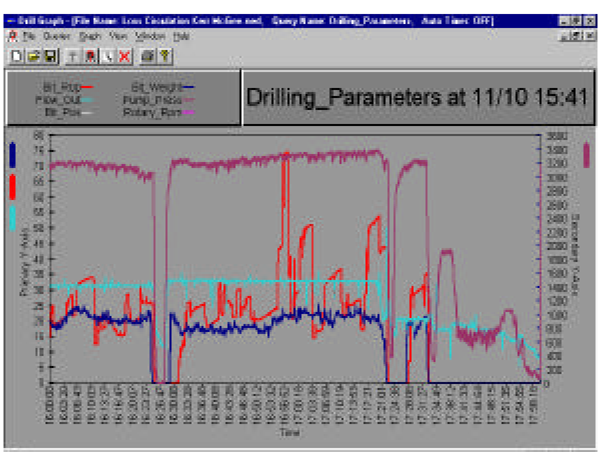
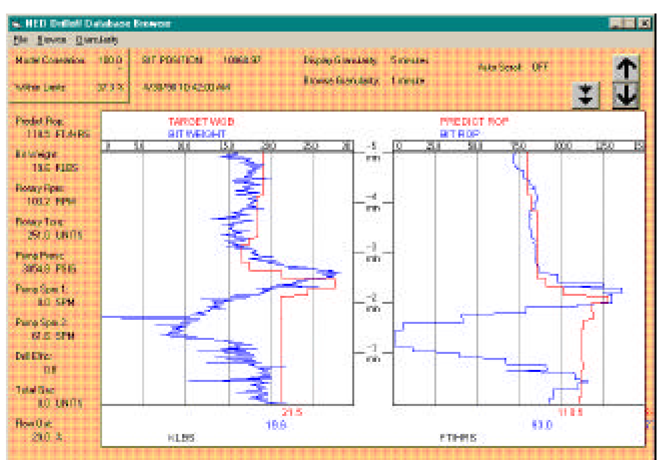


Figure 6. Drill-Smart screen



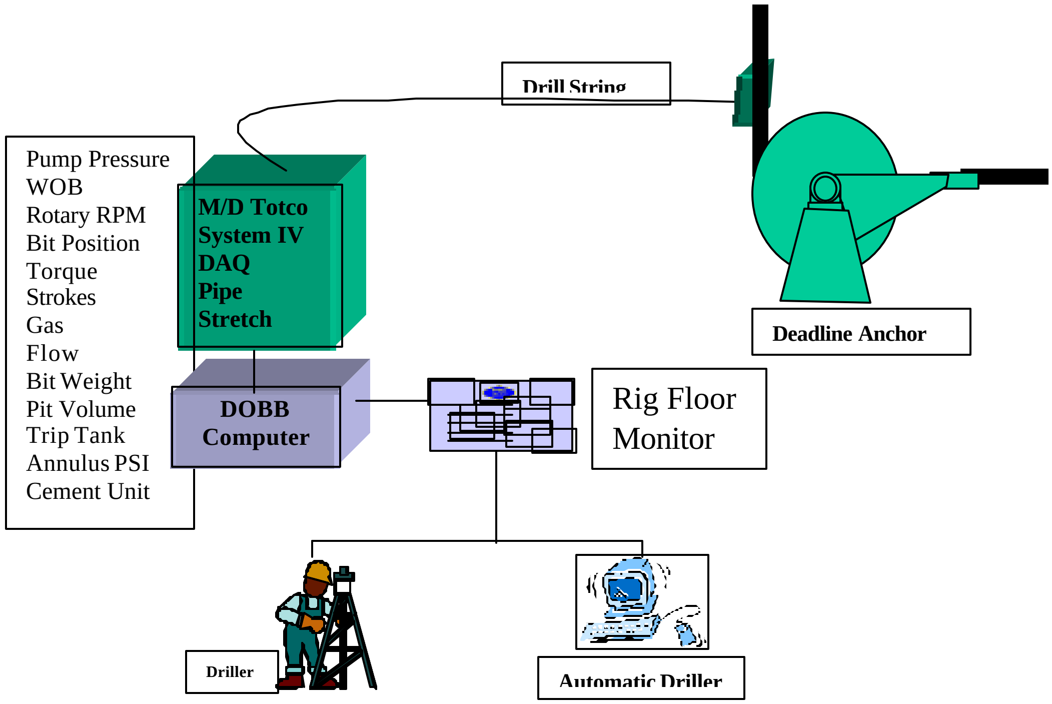
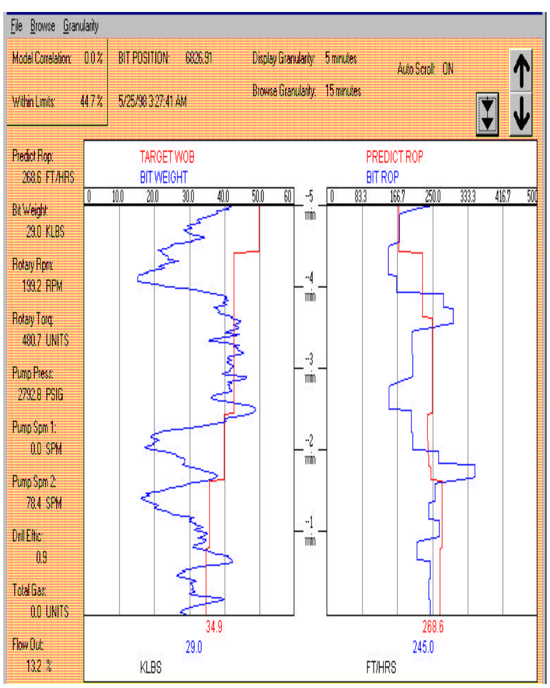


Figure 7. NDSSÔ Well Site Components



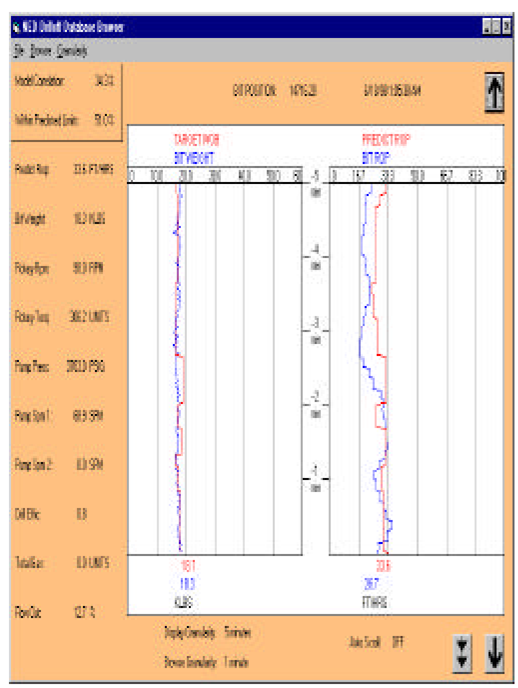


Figure 8. Drilling without NDSSÔ
Note the wide variations in weight on bit

Figure 9. Drilling with NDSSÔ
Note the consistent weight on bit

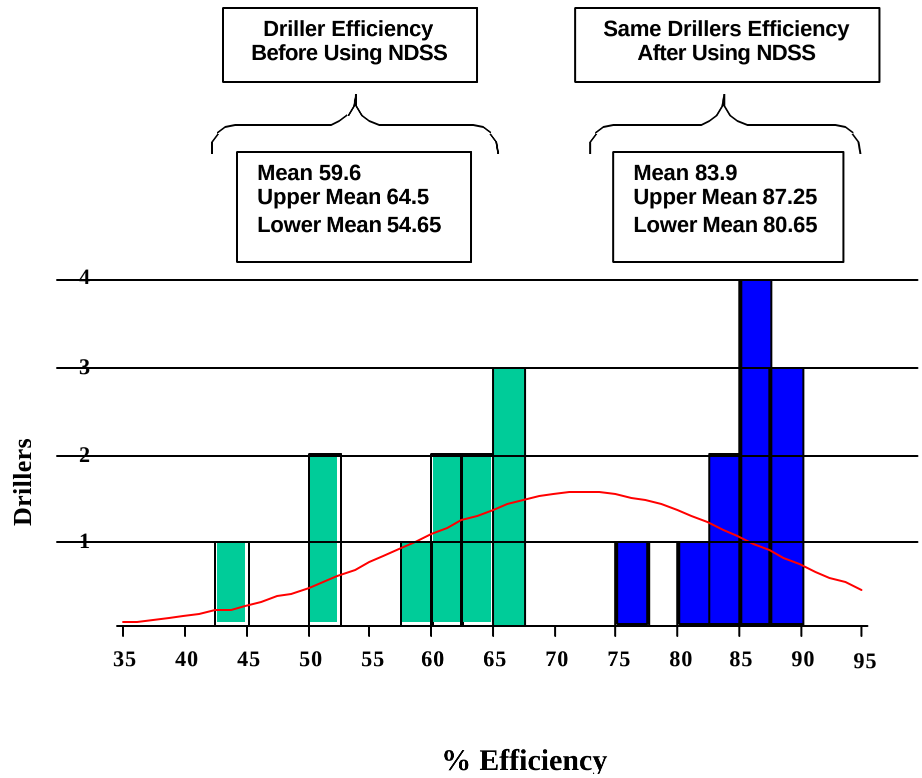


Figure 10. Drilling with and without NDSSÔ
Note the efficiency increase using Drill-Smart

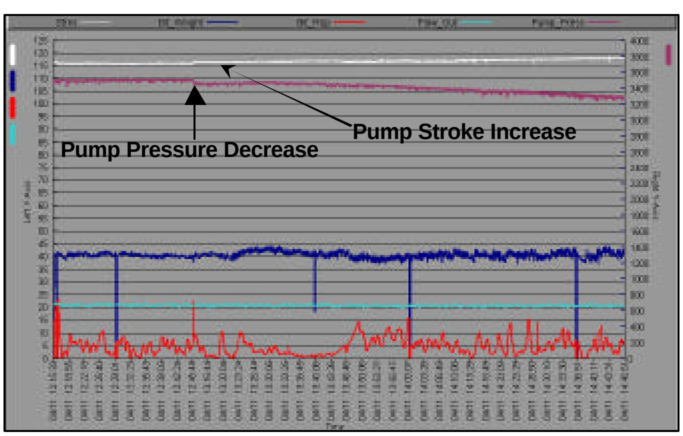


Figure 11. Drill graph event recognition screen. This screen is evidencing a drill pipe washout.

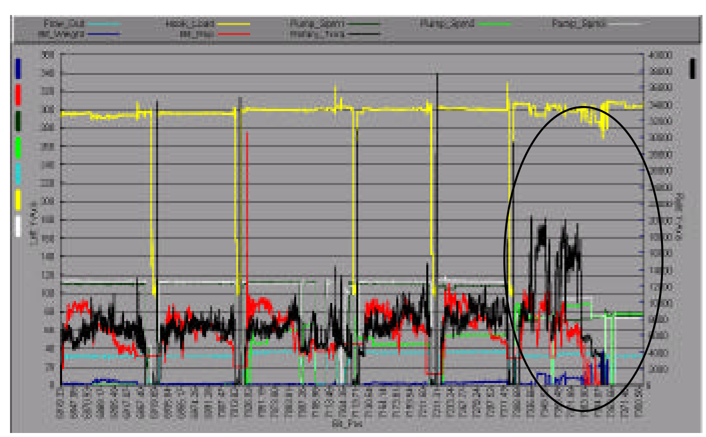


Figure 12. Drill graph event recognition screen. This screen is evidencing a mud motor failure and subsequent twist off after a connection.

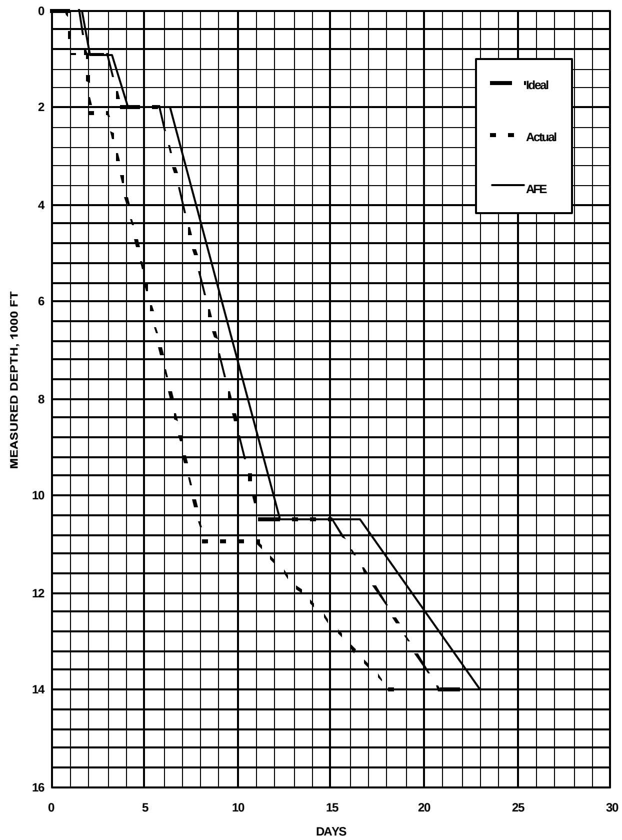


Figure 13. West Delta Days vs. Depth Curve

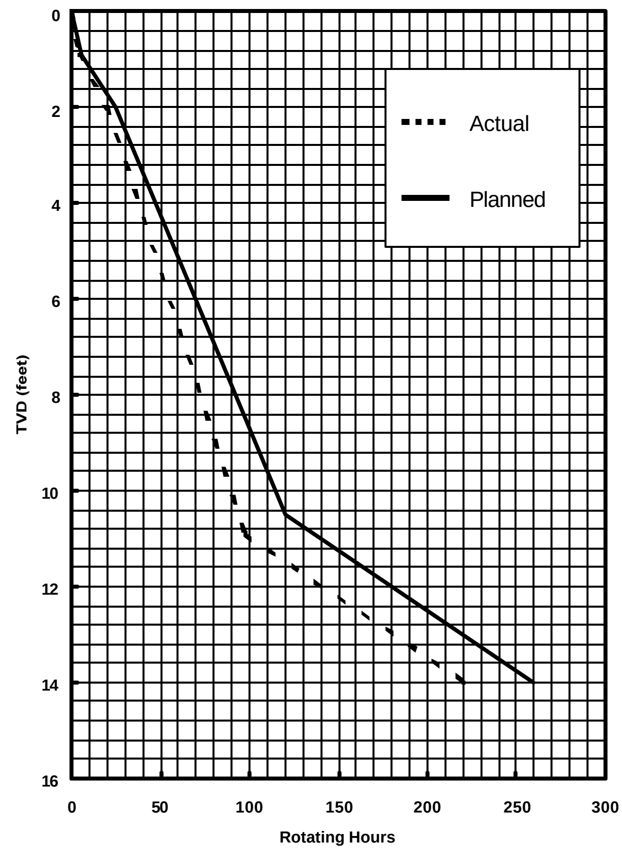


Figure 14. West Delta Rotating Hours Curve

Figure 15. Grand Isle Days vs. Depth Curve

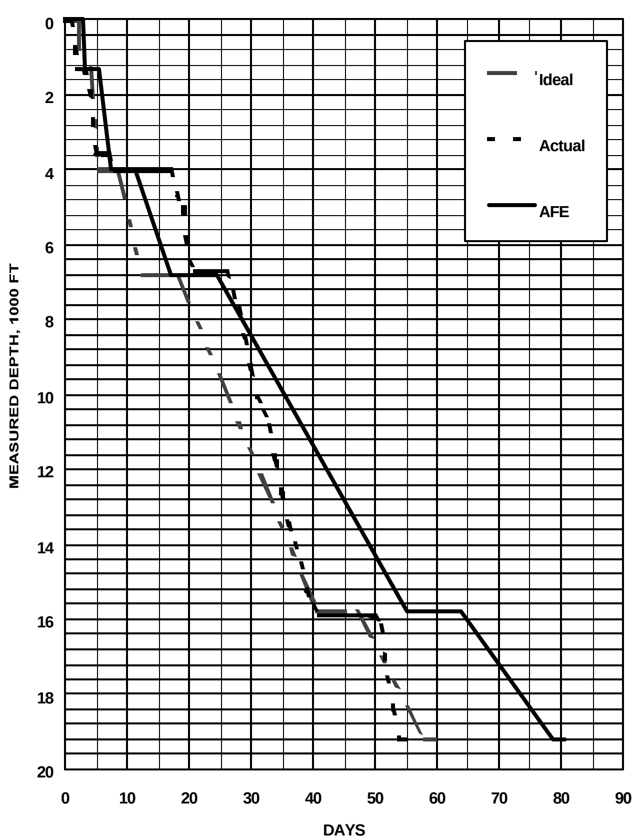
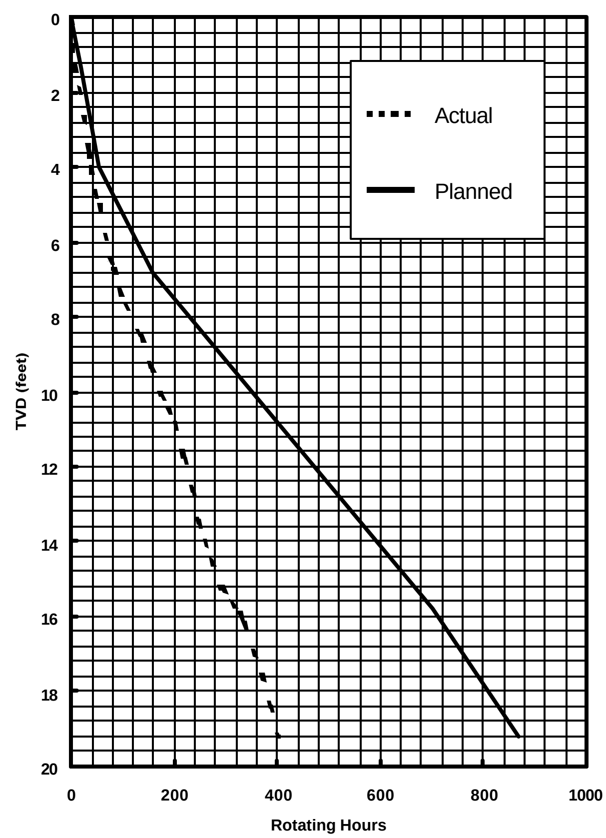


Figure 16. Grand Isle Rotating Hours Curve



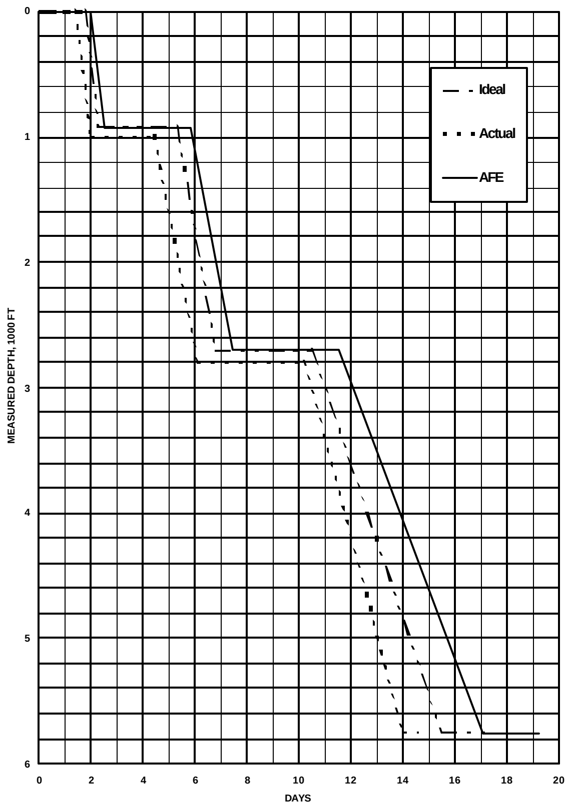


Figure 17. West Africa Days vs. Depth Curve

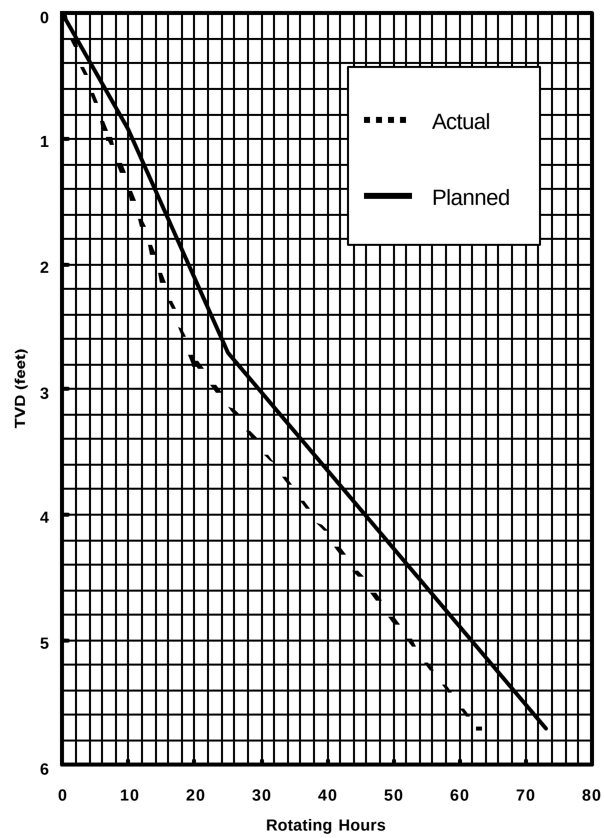


Figure 18. West Africa Rotating Hours Curve