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eDrilling Used on Ekofisk for Real-Time Drilling Supervision, Simulation, 3D Visualization and Diagnosis

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Abstract

eDrilling is a new and innovative system for real time drilling simulation, 3D visualization and control from a remote drilling expert centre. The concept uses all available real time drilling data (surface and downhole) in combination with real time modelling to monitor and optimize the drilling process. This information is used to visualize the wellbore in 3D in real time. *eDrilling* has been implemented in an Onshore Drilling Center in Norway.The system is composed of the following elements, some of which are unique and ground-breaking:

- An advanced and fast Integrated Drilling Simulator which is capable to model the different drilling sub-processes dynamically, and also the interaction between these sub-processes in real time. The Integrated Drilling Simulator is used for automatic forward-looking during drilling, and can be used for what-if evaluations as well.
- Automatic quality check and corrections of drilling data; making them suitable for processing by computer models
- Real time supervision methodology for the drilling process using time based drilling data as well as drilling models / the integrated drilling simulator
- Methodology for diagnosis of the drilling state and conditions. This is obtained from comparing model predictions with measured data.
- Advisory technology for more optimal drilling.
- A Virtual Wellbore, with advanced visualization of the downhole process. A new generation visualization system designed to integrate all participants involved, will enable enhanced collaboration of all drilling and well activities in a global environment.
- Data flow and computer infrastructure

eDrilling (Ref. 1) has been implemented in an Onshore Drilling Center on Ekofisk in Norway. The system has been used on several drilling operations. Experiences from its use will be summarized and presented; both related to technical and work process issues. The supervision and diagnosis functionalities have been useful in particular. The system has given very early warnings on ECD and friction related problems. This paper will present the *eDrilling* system used on a specific Ekofisk wells with focus on experiences from its use.

Introduction

The southwestern part of the Norwegian continental shelf, called the Ekofisk Area, contains eleven major chalk fields. The Ekofisk field is the first and main discovery, discovered in 1969 and put on production in 1972. The fractured chalk reservoir lies at a depth of 9500 – 10700 feet and is approximately 11.2 x 5.4 kilometers in area, with production coming from two zones Ekofisk and Tor. It is one of the North Sea Giants with a STOIIP of 7 mmbo!

Currently there are 4 fields in production, 4 fields abandoned with current production around 325,000 bbls per day of oil and 350 scf of gas per day. Water injection is currently used to maintain reservoir pressure, and approximately 900,000 bbls of water are injected each day.

There are over 150 wells that have been drilled on the Ekofisk, and due to the complexity of the field, with its numerous faults and fracture networks, location of injected water, and pressure uncertainties, all result in well placement challenges.

New wells are being drilled both as injectors and for production from newer facilities, and from jack-ups. Much of this drilling is supported from the Onshore Drilling Centre (ODC) located onshore about 280 Kms from the field. It is connected to offshore by high bandwidth fibre optic cables which allow high levels of communication and real time data/information transfer.

It was in 1998/1999, a 1143 kilometer long fibre optics cable with 24 fibre strands was run from Kaarstoe on the west coast of Norway, via the North Sea oil platforms Draupner, Ula, Ekofisk, Valhall and Murdoch, to Lowestoft in the UK. COPNo. utilizes part of the capacity of one pair of strands in this cable for a 2 x 155 Mbits/sec data connection between the Ekofisk field and the offices onshore. The Ekofisk area, which consists of many platforms, is interlinked with fibre optic connections or high-speed radio links, in turn meaning that the lowest bandwidth available to shore from any COPNo. platform on the Norwegian Continental Shelf is 155 Mbits/sec.

This huge increase in available bandwidth, compared with traditional offshore installations, has revolutionized the communication between onshore and offshore.

Key types of services delivered through the cable include:

- Telephony
- Video conferencing
- Closed Circuit Television (CCTV)
- Direct communication between handheld UHF radios offshore and phones onshore
- Wireless video and audio communication between VisiWear units offshore and PCs/video conferencing equipment onshore
- Wide variety of real time data transfers
- Remote support / remote control

Video conferencing, once regarded as too unreliable or cumbersome to use - or simply not feasible in an offshore environment - is now a business critical service within ConocoPhillips in Norway. About 2,500 video conference meetings are held each month, the majority of these between onshore and offshore. Moreover, the demand for point-to-point and multi-party conferencing continues to increase.

This technology enables multiple disciplines ranging from Operation Geologists to Directional Drillers to carry out much of their work remotely from the centre.

COPNo has been very supportive towards new technologies which can improve the effectiveness of drilling operations and can reduce drilling problems. eDrilling is the prime example of this.

Real Time modeling

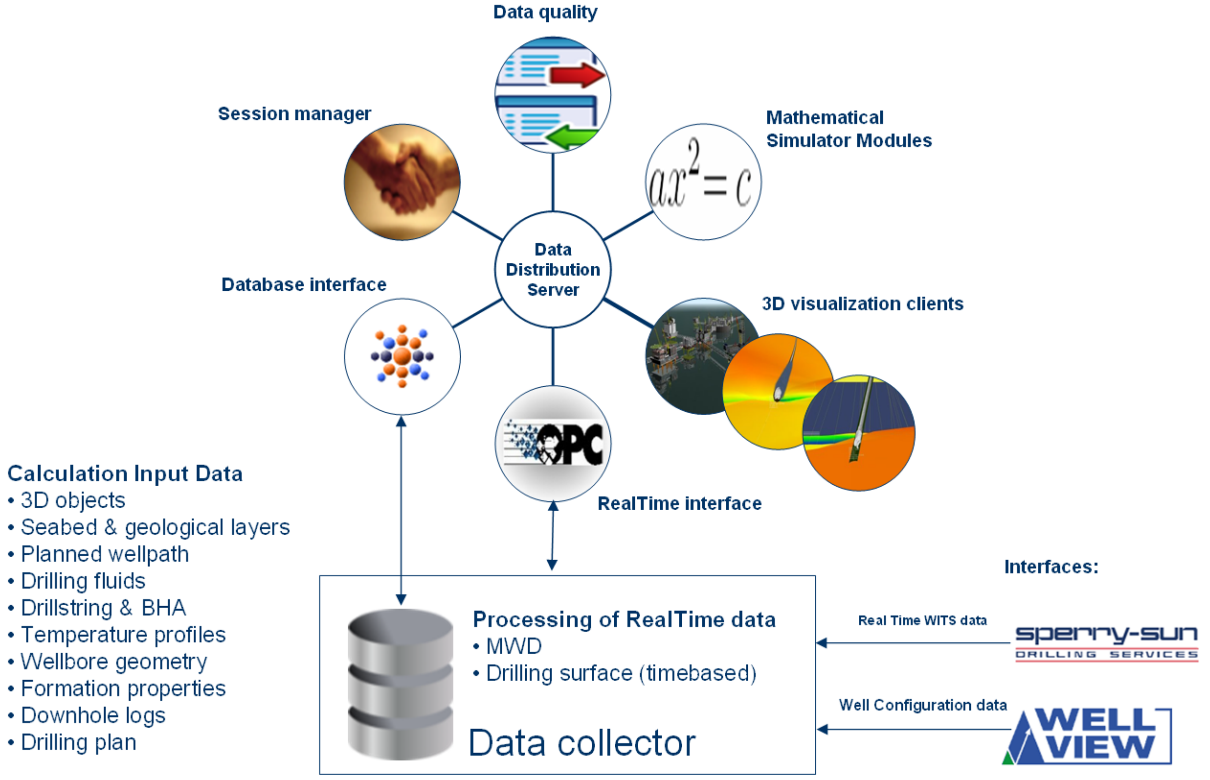
The key elements of eDrilling are real time simulation, visualization in a virtual wellbore and decision support. The infrastructure allows for simulation of the drilling sub-processes by integrated drilling models driven by the process itself. This RT enabled Integrated Drilling Simulator creates a “mirror” of the drilling process itself, and gives important information on key drilling parameters like hydraulics profile (ECD), temperature profile, friction conditions along the drillstring and wellbore, cuttings transport conditions, well instability tendencies, pore pressure ahead of drill bit, optimal ROP; all in real time.

The system also makes automatic diagnosis of upcoming drilling problems by combining real time simulations with drilling data.

The virtual wellbore is another key element of eDrilling. The 3D visualization of the drilling itself (drillbit, string, BHA etc) in real time is supplemented with VR visualization of simulation results. This makes the virtual wellbore the key tool to communicate well status as well as inform across boundaries (drilling, geology, asset team..) during the drilling operation.

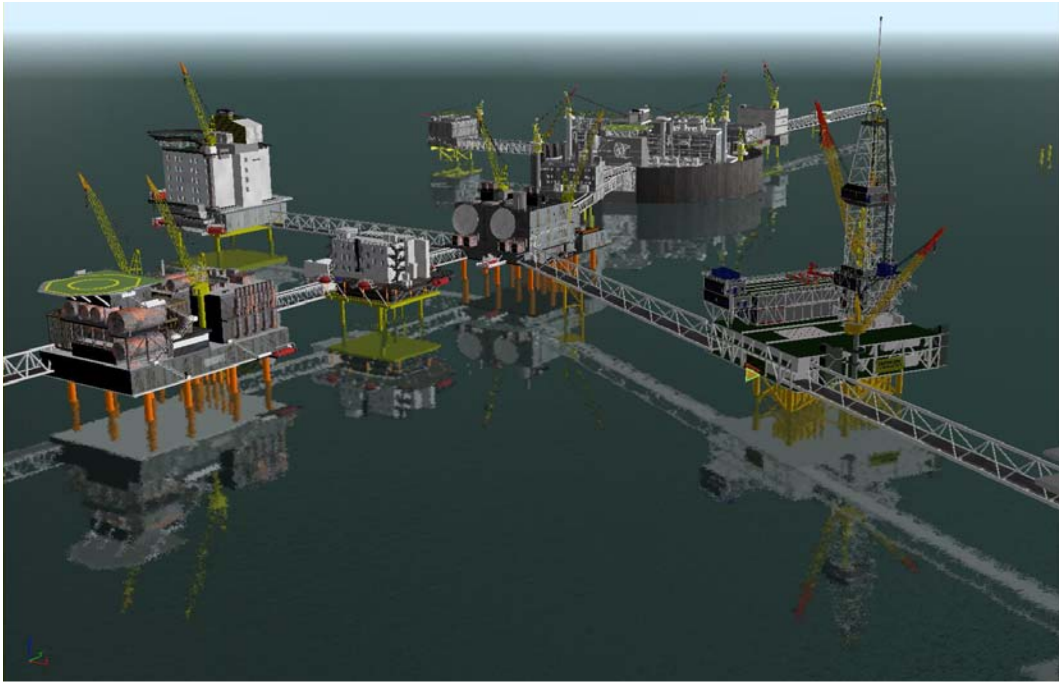
Data infrastructure on Ekofisk

The eDrilling system is collecting data from different data/information suppliers. On the Ekofisk pilot interfaces towards WellView (Reporting tool) and Sperry Sun (Mud logging and MWD tool) are established. The eDrilling system allows for integration/interface on Standard interface protocols like OPC, WITS, Profibus, WITSML, etc. Below is a picture showing the Infrastructure on the Ekofisk Pilot



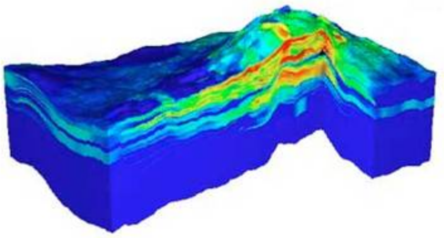
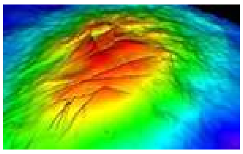
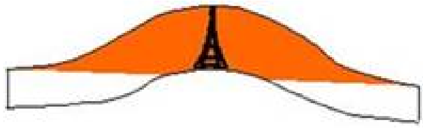
3D Visualization of Ekofisk Complex with 2/4-X

The eDrilling 3D engine has the capability to import 3D models with high complexity. Below is a picture from the eDrilling Graphical User Interface showing the whole Ekofisk complex.



Visualization of Geology on Ekofisk

The Ekofisk field was found in 1969, and has produced 2.1 billion barrels of oil and 124 billions m3 gas by 2004, and will still be in production for many years. Average production is 350.000 barrels oil/day, 350 million of standard cubic feet with a water injection of 900 000 barrels per day. The thickness of the Ekofisk reservoir complies with the Eiffel tower. Orange indicated oil.

In the eDrilling project the focus related to Geology is to show the user the actual layer and give Real Time information to the Driller and other users about when equipment is passing through different formations/layers (see picture below).

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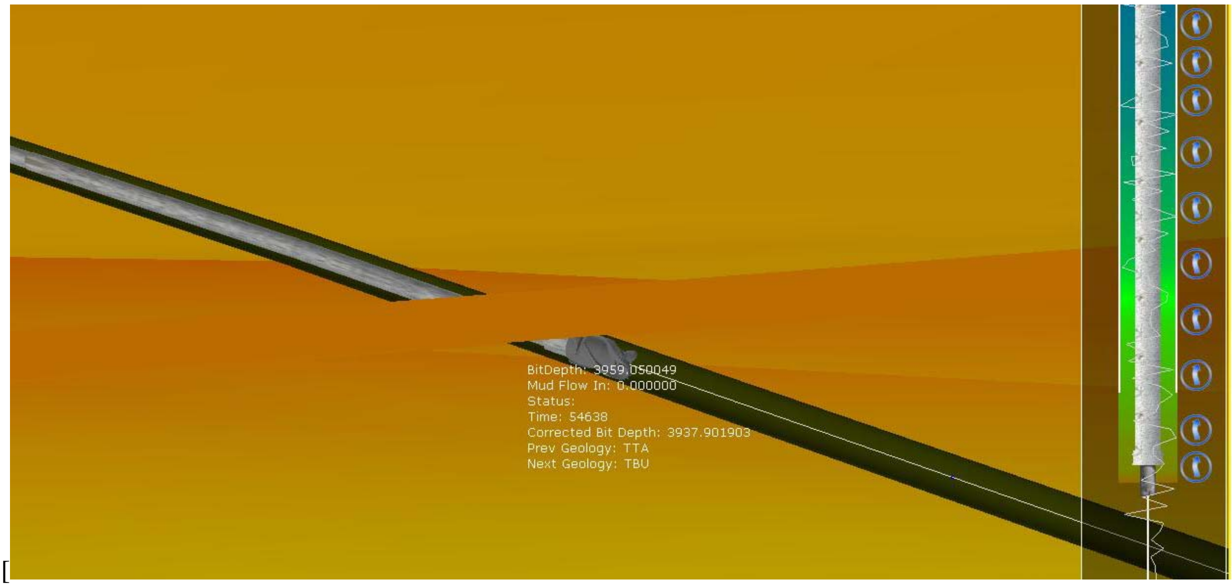
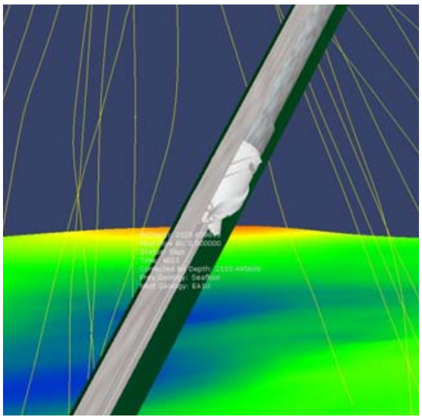
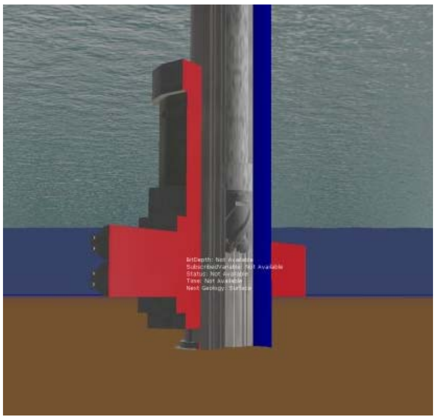


Virtual Well

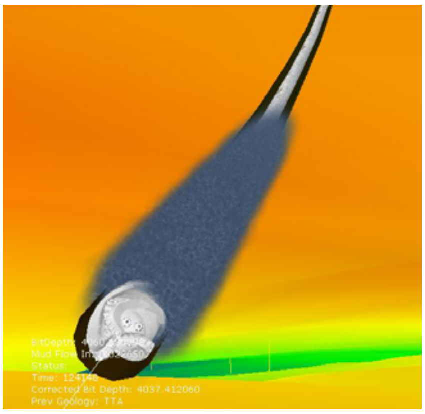
The eDrilling 3D visualization system enables the user to get a true overview of the well by displaying all relevant information in RealTime 3D. Below are some typical examples of visualization:



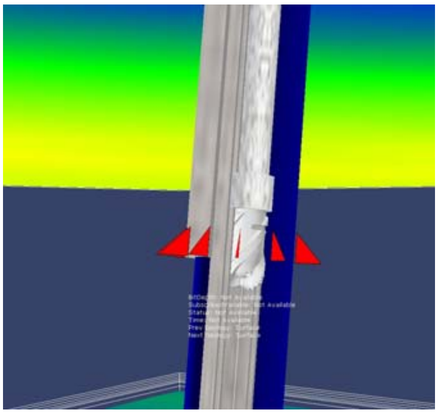
Bit in Casing



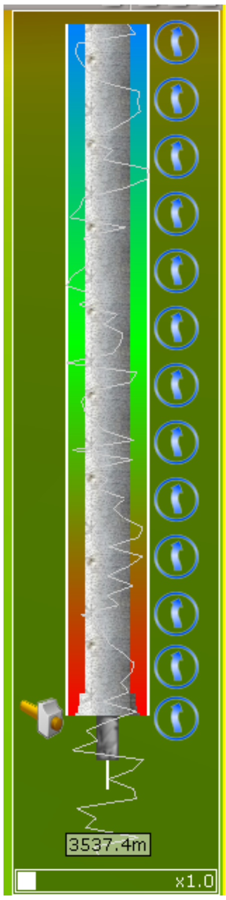
Bit in BOP



Drilling



Bit passing Casing shoe



2D view showing RealTime Simulator results, diagnosis icons and Forward-looking on ECD

Well description with drilling experiences

The Well studied in this paper was drilled out from the main well, through 12 $^{1}/_{4}$” casing. The data presented here were recorded when drilling inside 7 $^{3}/_{4}$” liner with a 6 $^{1}/_{2}$” bit using a rotatable steering system GEO-PILOT. The drillstring included a commonly used suite of MWD and LWD sensors and a formation tester.

This study covers tripping into the well, conditioning the mud, washing down the last 62 meters (203 feet) of the existing well before drilling another 200 meters (656 feet). There was no significant change in azimuth.

The section was drilled without any major problems. The rate of penetration varied somewhat during the run and averaged about 6 m/hr (20 ft/h). Drilling was interrupted at several points to take formation pressure measurements.

Inclination started at 60 degrees and was gradually built up to 73 degrees at the end of this study. The well continued for another 200 meters (650 feet) before progress was stopped because of faulty MWD communication.

Supervision of Torque & Drag

Wellbore friction was monitored through the test by the Torque and Drag Module (TDM). Hookload increased as the drillstring was tripped into the well, but the friction coefficient was computed to drop slightly through this phase. When conditioning the lower part of the well, the hookload when slacking off was seen to increase compared to hook loads observed in the tripping phase. There was a further increase in hook load for slacking off on entry into the drilling phase.

The apparent increase in friction could be misleading. Is the increase due to cuttings bed? Sticking? The friction coefficient calculated by the Torque/Drag module is stable over this period. These increases are attributed to changes in rotary speed and running speed. Monitoring the friction coefficient in real time lets the driller know that all is well and that the increases in hook load are not cause for alarm.

This is demonstrated in Figure 2 where hook load for slacking off and the friction coefficient calculated by the TDM are plotted against bit depth. An increase in hook load of 10 tons is explained by the T/D model and thus gave no cause for alarm.

ROP analysis

The Data Quality Monitor (DQM) checks incoming data for possible errors and suspicious data are flagged. In addition, the DQM analyzes time based data to generated improved values for the rate of penetration (ROP) and weight on bit (WOB). This is accomplished through a combination of physical models and rig specific calibrations. Modern bits, particularly in smaller diameters use a very small weight on bit. A measurement error of a few tons may represent a 100 % error in WOB.

The drillability, here defined as the value of ROP divided by WOB is a good indicator of changes in lithology. Monitoring drillability is a good way to locate important milestones when drilling a well and can help to determine the correct casing point. Errors in WOB make this difficult as the drillability can vary wildly due to errors in both ROP and WOB.

This is illustrated best by looking at the drillability before and after a connection is made. Normally, the drillability would not change when a connection is made as we will probably be drilling in the same formation. However, due to systematic errors in WOB, the drillability often exhibits a significant change over a connection. This is demonstrated in Figures 3 and 4 where drillability is calculated for the raw data for ROP and WOB and for the DQM generated ROP and WOB. The raw data exhibit essentially two drillability values (3.4 and 4.7) separated by the connection point. DQM removes this discrepancy.

Supervision of ECD with automatic diagnosis embedded

With the eDrilling system ECD will be continuously monitored and compared to calculations done by an advanced dynamic pressure and temperature model (Ref. 2). The model will be continuously calibrated provided there are sensor readings that are considered sufficiently reliable for that purpose. Things like sensor drifting and invalid data points will have to be considered and handled properly. If that is not possible a more manual calibration based on human analysis of data while performing operations will be an option.

The examples from the Well illustrated by Figures 5-7 show how flow model calculations are performed with input of real drilling data. Eventually this will happen in real time, but at this stage data was recorded while replaying data after operations had finished. Figure 6 shows that calculated standpipe pressure fits well at high pump rates. Although a slight calibration was done this supports the calculated bottom hole ECD in Figure 7. Accurate pore and fracture pressures were not available while writing this paper. When those are available, calculated ECD, both at the bottom and at other positions along the open hole section, will be compared continuously to given pressure profiles, and if getting close to or exceeding boundaries a visual notification will be triggered in the 3D view, see Figure 8. When well pressure is increased above pore pressure the message shown will still be available to let the drilling crew easily access the history of the operation, but clearly distinguished from live messages.

Diagnosis of problems

The ECD example above shows how advanced real time models can help to make earlier and more reliable detection of upcoming unwanted conditions. Without going into detail we list here a number of other examples that are or will be part of the system.

- Measured well pressure is changing significantly and/or quickly with no obvious cause (i.e. not reproduced by model).
- The axial and rotational friction coefficients will be back-calculated based on measured hook load and torque, and warnings will be given if the value goes outside a predefined range or changes rapidly.
- Weight on bit is too high or too low, e.g. due to significant vibrations.

In addition early warnings will be given when models predict high risk of unwanted events like gain, loss, poor hole cleaning, getting stuck, instable wellbore, etc., before the events are actually detected. Some of these are discussed in more detail in Ref. 4.

Work process consequences of eDrilling

The purpose of eDrilling and the real-time enabled Integrated Drilling Simulator is to optimize drilling by utilizing simulations and measured data, reduce frequency of “catastrophic” drilling problems, and give automatic diagnosis and decision support. Potential users of the system include:

- Offshore: Mud eng., driller, geologist, drilling sup., drilling eng.
- Onshore: Operations supervisor, driller, lead drilling eng., asset support team (reservoir), drilling eng.

The system has several potential application areas as illustrated in the figure below:

During planning/design:

- To test the Drilling Plan as well as to investigate various what-if scenarios (Drill the well on computer)
- Link to earth model

Real time link to operations:

- Drilling supervision and control (e.g. well completion, interventions)
- Real-time diagnosis and advice
- Forward simulations.

During training and post analysis (replay of operations):

- Assist in knowledge building and experience transfer
- Efficient use of experience
- Update model for future wells

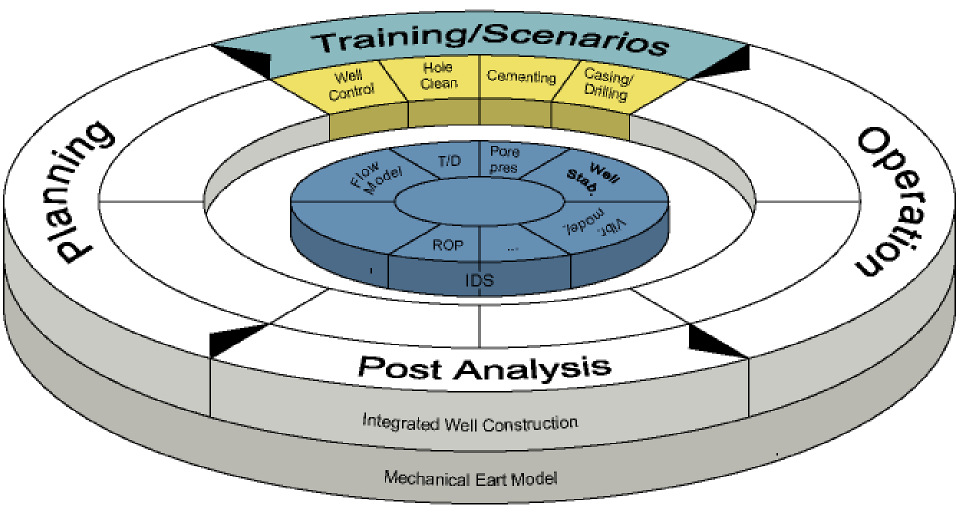


Figure 1 Future use of the Integrated Drilling Simulator

There are several challenges related to evaluation of technical steps to reach future work processes;

- *How to get the relevant disciplines to use the drilling simulator?*

The disciplines must see what they can gain from using the eDrilling system. Use of the system must be integrated into current work processes in the organization and implemented into operation gradually.

- *How to get data into the system at the right time?*

One issue is integration of online data. Another is how to get the data that is not accessible online, but needs to be entered manually or from various electronic document formats. The databases should as far as possible be built from automatic data collection. Several different companies may be contracted for shorter or longer times. This raises challenges related to standardization.

Weaknesses of today's work processes in drilling. One critical problem is collaboration related to the way important process parameters are collected, interpreted and used in operative execution of the drilling process. This often happens through casual and random observations and qualitative judgments without sufficient empirical basis. The involved actors (operators and contractors) lack a total and shared overview of the process including relationships between the various actors, and how different parts of the drilling process are connected and influence each other. In isolation, the individual observations may not seem critical. There is an urgent need for the involved actors to have a common picture. The need for creating and sharing this holistic picture as a common frame of reference is not met in today's work process, some times a fatal incident turns out to be the result.

A necessary step to improve today's situation is to implement a change process towards a more automatic, shared and structured practice of smart collaboration implying that the drilling actors (including offshore and onshore personnel, drilling contractor and service providers), as one unified team, can work and operate more efficiently in a collective way by means of real time collaboration. This new collective practice entails a stronger integration between implementation of new technology and continuous improvement of work processes.

Emergence of new work processes. Three drivers have been identified for the implementation of the eDrilling / Integrated Drilling Simulator in the drilling organization:

- Less personnel needed offshore
- More efficient drilling processes
- Higher quality in decisions through smart collaboration

Change of roles. The use of eDrilling will have consequences for the drilling organization. Better utilization of available data through real-time data access combined with a new knowledge sharing and collective way of working, will fundamentally change some of the roles in today's organizations, both onshore and offshore. The following changes in roles are expected:

Offshore roles:
- *Driller:* Access to more data will change the driller's role from being a supervisor for the drilling crew to become a drilling process operator. The drilling simulator can be integrated in the drillers instrumentation.
- *Suppliers/contractors:* The situation today is that different suppliers/contractors are located in separate containers, looking at different data. This gives each involved actor access to a fragmented view of the overall picture. With better and more integrated access to data, fewer experts can be used for surveillance. It would also be possible to do this job from onshore.
- *Operative roles:* There will still be need for operative roles that are responsible for the actual carrying-out of the drilling process. For these roles the drilling simulator provides opportunities for training and visualization of activities that have taken place during their 4 weeks off before the start of a new shift.

Onshore roles:
- *Responsible for wells:* The functionality eDrilling provides makes it possible to support the offshore operation using a minimal staff. This allows for an onshore support group to assist several drilling operations from an operation centre. Possible roles for such a centre include experts on well placement and geosteering (if 24/7 onshore manning), planners and drilling engineers
- *Mud engineer:* This role may be moved onshore or replaced entirely by the drilling simulator and improved instrumentation.
- *Integrated Drilling Simulator IDS/eDrilling support:* There will be need for a role that is responsible for the quality assurance of data going into and coming out of the IDS etc. Also support for the modeling and diagnosis will be needed; especially in a transition period until the simulator is verified and accepted.

Work processes that will be supported by the eDrilling/Integrated Drilling Simulator

Visualization

One advantage of eDrilling is the ability to visualize different kinds of information in different work processes. The usefulness of the visualization depends on how detailed and what kind of information is visualized. This must be useful information about the well and borehole, including real-time data such as:
- Monitoring cuttings, stabilizers, bit, friction. This can give better understanding for what is happening for the driller.
- Show ECD and mud temperature in different parts of the borehole. This can give information about pressure control, hole stability.
- Gamma-ray curve to see different layers/formations (lithology). This can be collected or interpreted from the real-time lithology.

- Vibrations
- Caliper
- Tightspots (overpull over a threshold)
- Show subsea facilities like pipes, ROVs, BOP.

These visualizations may be useful for the driller and others during operations. They can also be useful as a tool for communication between different disciplines, e.g. during well planning where different actors view the same information and can function more like a team.

Surveillance / diagnosis

- Various surveillance data are interesting for a drilling process engineer / drilling optimizer, wellsite geologist, drilling supervisor.
- Uncover beginning instability in the formations, influx or lost circulation and stuck pipe (today, the driller and assistant driller and some drilling supervisors usually are the ones who detect deviations).
- Engineers must be used to verify diagnoses.
- Perform measurements to be able to optimize drilling speed.

Forward-looking

This is useful for the driller, but the driller is not able to do this during operation. Thus forward-looking must be performed by a “drilling optimizer”.

Other potential processes

- Cementing, casing
- Completion, perforation, inflow profile in well where this moves over in production.
- Training
- Experience transfer, can replay drilling activities.

Future steps for work process change

First eDrilling will be implemented into existing work processes emphasizing operational execution of the drilling process offshore in collaboration with onshore support . Secondly more basic organizational changes caused by eDrilling will be gradually realized, e.g. directing and execution of the drilling process from onshore.

The eDrilling pilot implementation has now reached a phase where mapping of some of the expectations surrounding the implementation in ConocoPhillips can be done. A number of different users, supporters and developers have been interviewed in order to create an overview of experiences and expectations in relation to the implementation of the eDrilling type of technology. The interview/mapping is focusing on how the user can use this technology to improve job performance. These are some typical questions that will be mapped:

- I think eDrilling will be useful in my job.
- Using eDrilling will help me do a better job.
- It will be easy for me to become skilful at using eDrilling.
- It will be easy to use eDrilling along with the other tools I am using.
- Using eDrilling is a good idea.
- Using eDrilling will make work more interesting.
- People who influence my behaviour / are important to me think that I should use eDrilling.
- In general, the organization supports the use of eDrilling.
- I have the knowledge and resources necessary to use eDrilling.
- I can get assistance from a specific person (or group) when system difficulties occur with eDrilling.
- I intend to use eDrilling in the near future.

Data Quality Demand

Through the course of developing the eDrilling system, we have analyzed time-based data from a number of wells recorded for several oil companies. This has revealed many problems and errors with this kind of data. We have observed obviously miscalibrated data, missing data, and cases where signals were recorded from the wrong sensor. Some errors come from the sensors themselves while others are generated along the complex path from sensor to data base (Ref 3). In addition, it is observed that signals are not synchronized. This can happen when signals are treated and sampled differently.

We think that through the use of rig data in real time, one can take a more proactive role in eliminating these errors. The Data Quality Monitor is a good start in this direction.

Conclusions

The first version of a comprehensive system that integrates advanced modeling and modern 3D visualization with rig operations in real time has been tested versus real drilling data. This system contributes through combined use of advanced modeling, automatic diagnosis, good visualization, and distributed human expertise to decision support and more optimal drilling operations.

Acknowledgements

The authors want to thank ConocoPhillips and NRC Petromaks Program for supporting the development of eDrilling. Furthermore the SFI "Center for Integrated Operations in the Petroleum Industry" is also thanked for supporting this work.

References

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4. Rommetveit, R., Bjørkevoll, K. S., Ødegård, S. I., Herbert, M., Halsey, G. W., and Kluge, R.: "*Automatic Real-Time Drilling Supervision, Simulation, 3D Visualization and Diagnosis on Ekofisk*", SPE 112533, presented at the 2008 IADC/SPE Drilling Conference held in Orlando, Florida, U.S.A., 4–6 March 2008.

Appendix. Figures

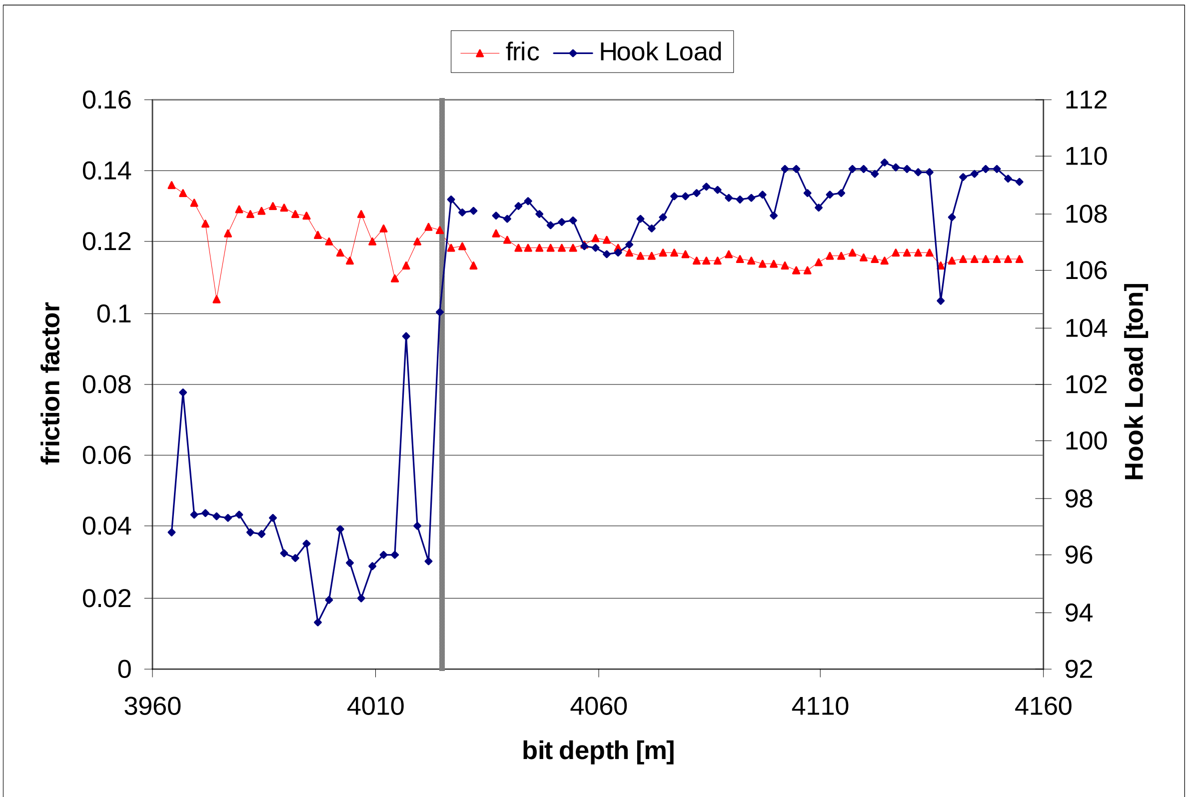

Figure 2: The red line gives the friction coefficient from the TDM and the blue data gives the hook load. Data to the left of the vertical bar were recorded while washing down the lower part of the well while data to the right of the vertical bar were recorded while drilling.

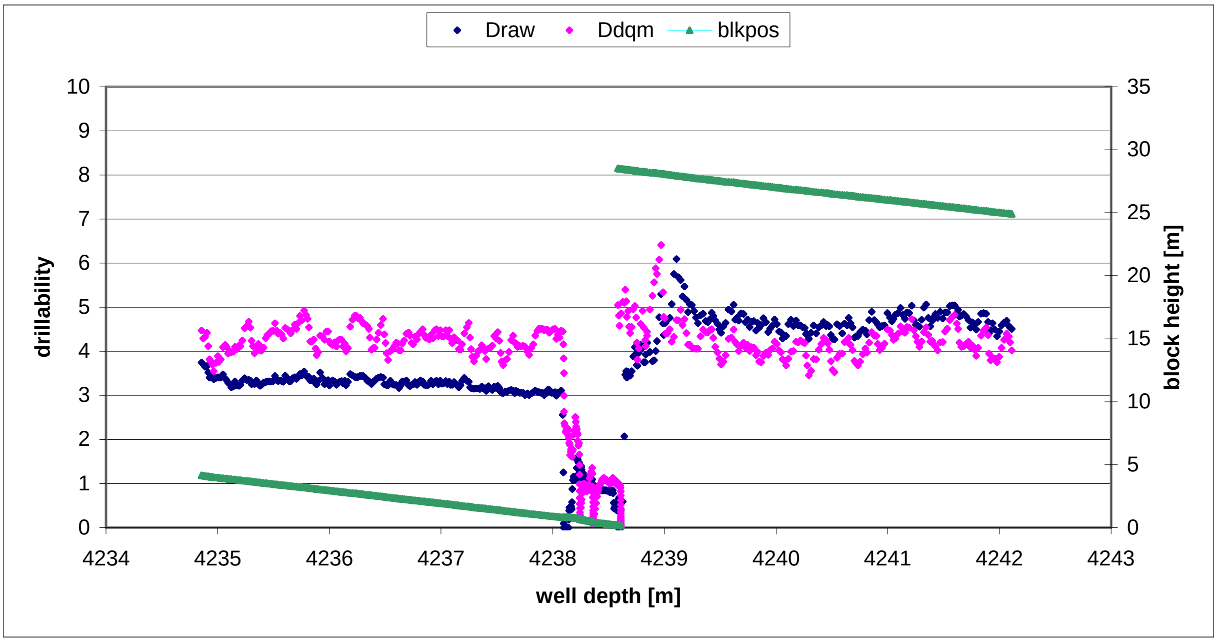

Figure 3. Plot of drillability versus well depth for raw data and DQM generated data.

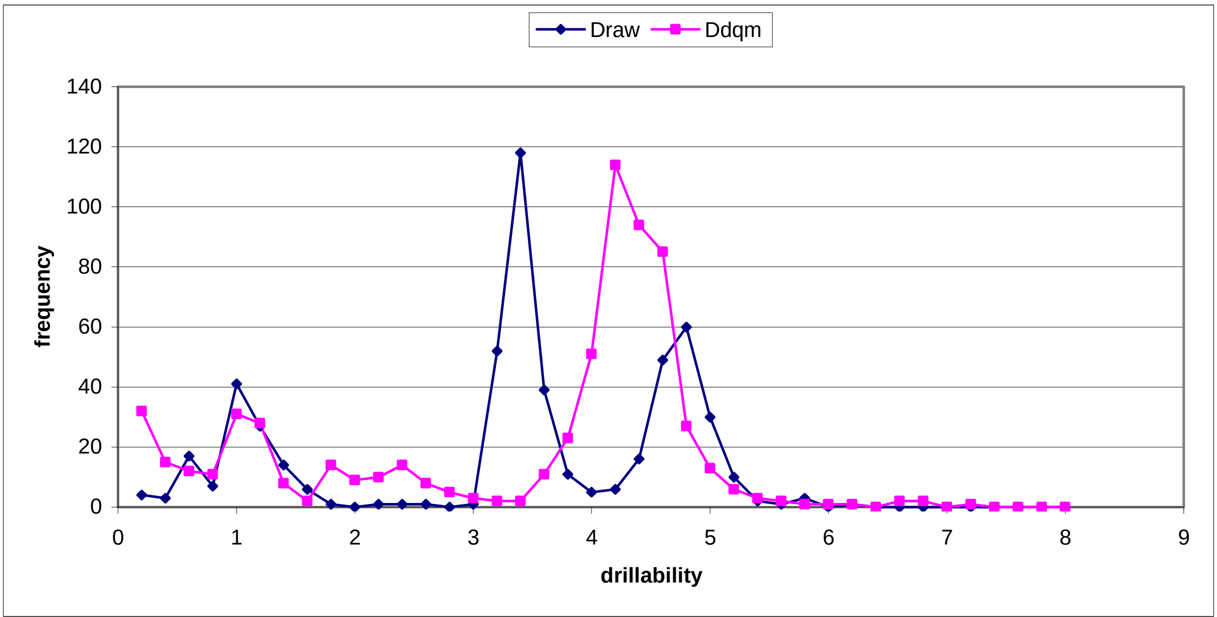

Figure 4. Distribution of drillability values for the data shown in the figure above. The two larger peaks in drillability for the raw data are combined into one peak in the DQM data.

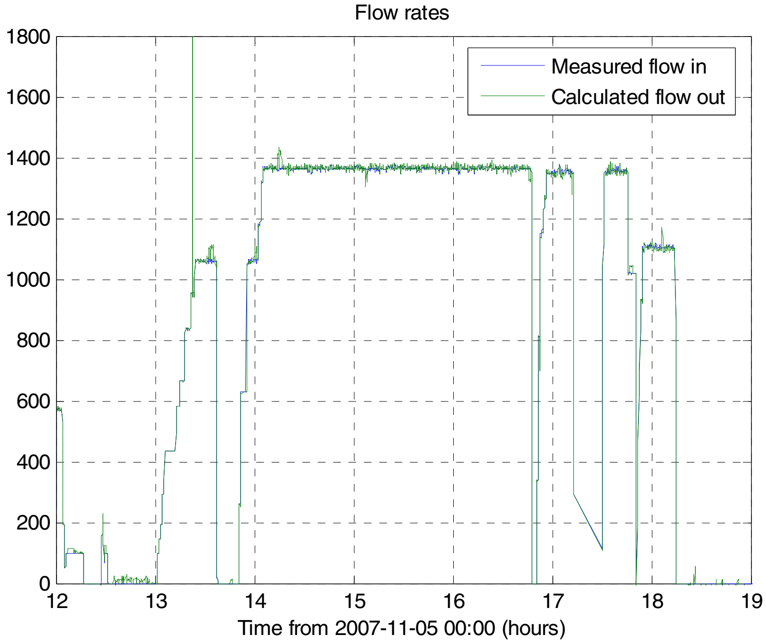

Figure 5: Pump rate while washing/reaming in (12-14 hours), drilling 18 m (14-16.8 hours), back-reaming, and tripping out (last half hour).

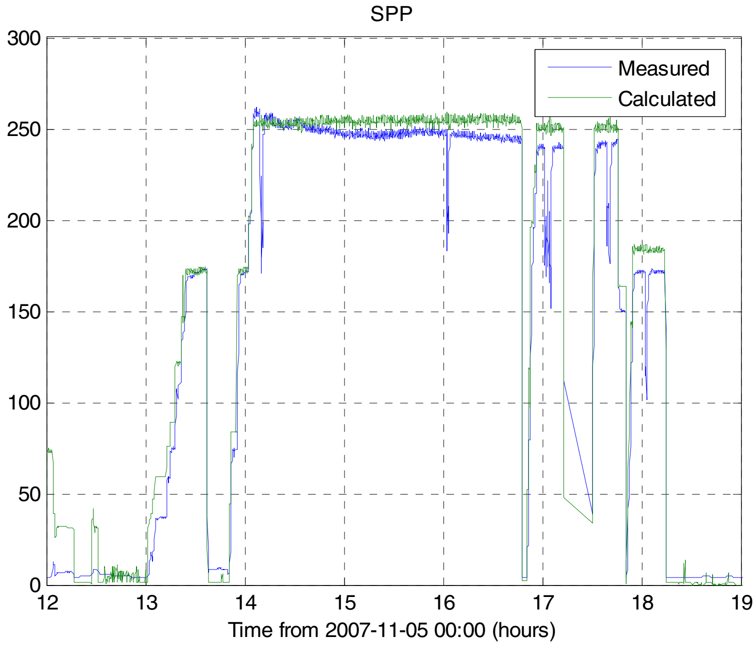

Figure 6: Standpipe pressure, same period as Figure 5.

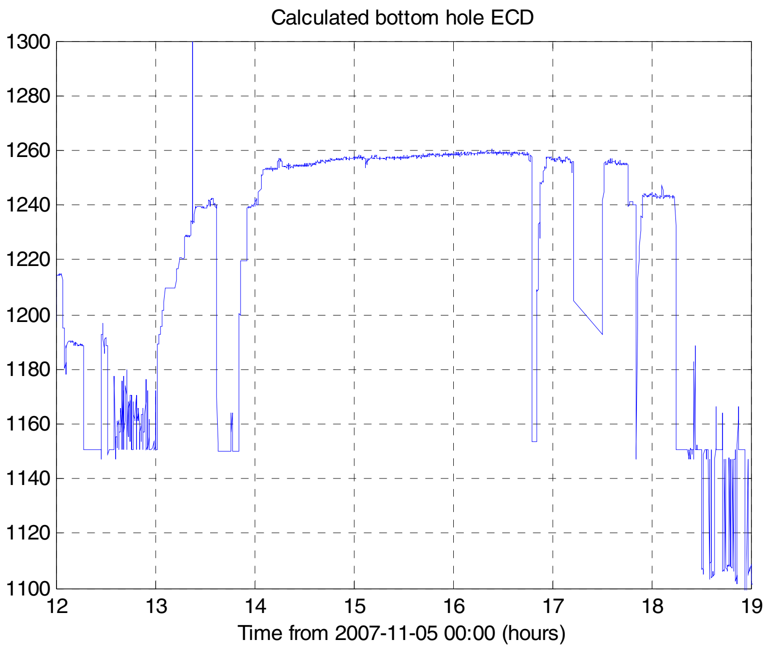

Figure 7: Calculated bottom hole equivalent mud weight, same period as Figure 5.

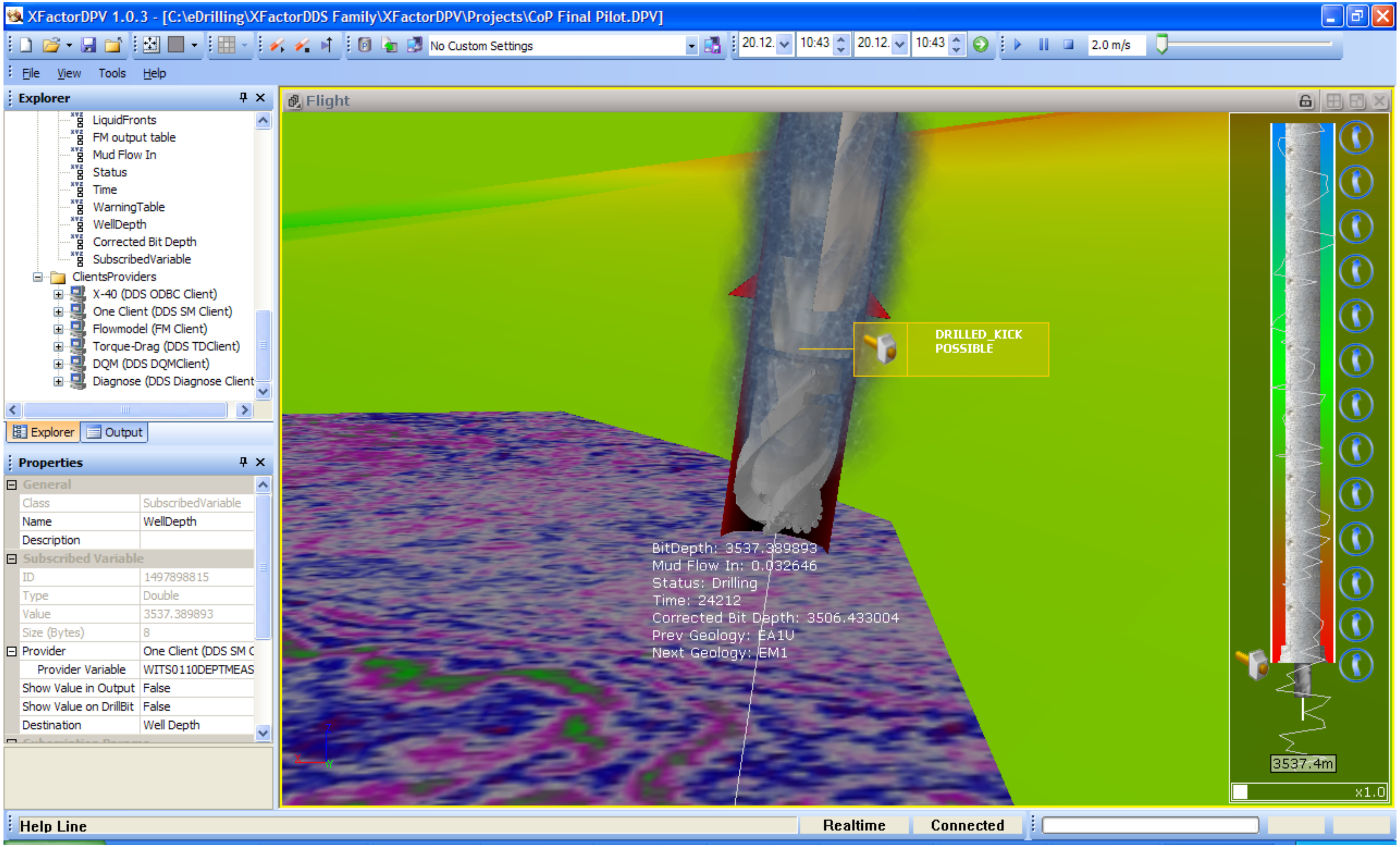

Figure 8: A kick alarm as displayed by the 3D view. The message "Drilled Kick Possible" pops up when calculated well pressure is close to or below pore pressure somewhere along the open hole, but no gain has been detected yet.