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Advanced Dynamic Training Simulator for Drilling As Well As Related Experience from Training of Drilling Teams with Focus on Realistic Downhole Feedback

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Abstract

The paper presents a highly advanced training simulator that combines an advanced top-side simulator with a dynamic down-hole simulator with an advanced transient integrated hydraulics and thermal wellbore model and a dynamic torque and drag model. The simulator is aimed at drilling and well operations, and is able to handle most of the normal operations, including high pressure high temperature (HPHT) wells, through-tubing rotary drilling (TTRD), extended reach drilling (ERD) and managed pressure drilling (MPD).

The underlying simulator technology is modular, allowing for new modules to be added at a later stage. For instance, MPD control systems can easily be added to the simulator, allowing for training on an MPD operation with both the drilling crew and the MPD supplier. The simulator is able to use pre-programmed scenarios, replay, fast forward and rewind to facilitate efficient training and review sessions

Moreover, the simulator is designed to provide realistic personnel training on emergency procedures and operations such as well control in a safe environment, thereby limiting the human factor in critical operations as well as possibly improving the procedures by frequent use and revision. Also, the simulator allows for integration of HSE in early well planning through simulator training on the actual well to be drilled.

The main innovation is to use dynamic models verified in real-time operations together with an advanced top-side drilling equipment simulator for training on well specific scenarios.

The value added for the industry is to give the drilling and/or engineering teams a possibility to verify and train on identified risk elements prior to drilling a well, as well as retrain during the operation on a “true” virtual copy of the well.

So far more than 60 drilling teams have experience from training, and the feedback has been very positive.

The paper will present the simulator as well as experiences from typical training cases on challenging wells.

Introduction

A highly advanced training simulator that combines an advanced top-side simulator with a high complexity and dynamic down-hole simulator has been developed. The simulator is aimed at drilling and well operations, and is able to handle most of the normal operations, including high pressure high temperature wells, through-tubing rotary drilling, extended reach drilling and managed pressure drilling.

Moreover, the simulator is designed to provide realistic personnel training on emergency procedures and operations such as well control in a safe environment, thereby limiting the human factor in critical operations as well as possibly improving the procedures by frequent use and revision. Also, the simulator allows for integration of HSE in early well planning through simulator training on the actual well to be drilled.

Such simulator training will also reduce the time that is used for training offshore, increase operational understanding and improve communication between driller and other personnel.

The underlying simulator technology is modular, allowing for new modules to be added. For instance, managed pressure drilling (MPD) control systems can easily be added to the simulator, allowing for training on an MPD operation with both the drilling crew and the MPD supplier. The simulator is able to use pre-programmed scenarios, replay, fast forward and rewind.

The basic philosophy for the simulator system was presented in ref. 1.

Down hole models

The models that form the background of the downhole models are the result of accumulated knowledge from continuous R&D and modeling in drilling. This knowledge is assembled in an Integrated Drilling Simulator IDS. Models with the appropriate degree of complexity have been selected, and the models have been improved where it has been seen as necessary, and re-implemented using methods that are optimized with respect to challenges in real time applications and training; see ref. 2.

The model basis for the transient and steady state applications has been built with focus on:

- Accurate representation of the physical system.
- Flexibility.
- Requirements related to real time applications and training:
- High degree of robustness, also when driven by real time data like pump rate, rate of penetration, drillstring rotation rate, torque, and inlet temperature.
- Sufficient calculation speed under relevant conditions.

The most relevant models for training are: Flow/hydraulics including temperature, torque/drag and rate of penetration (ROP). Some of these models will interact with the mechanical earth model (MEM) and related data as well as with each other.

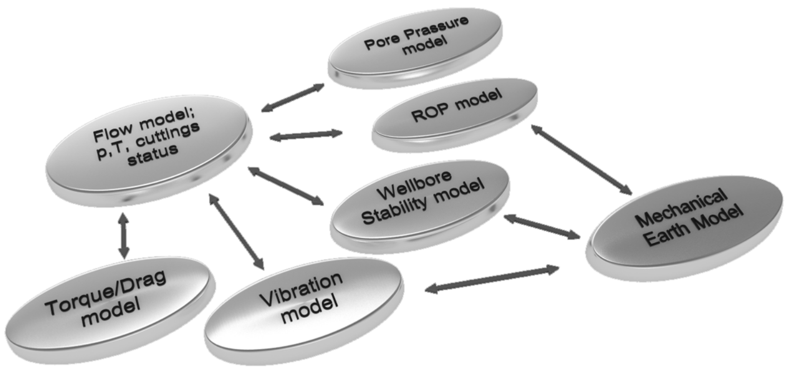


Figure 1 Sketch of how different sub-models interact in the Integrated Drilling Simulator

Some of the elements of the integrated drilling simulator are described in more detail below.

Downhole Pressure and Flow.

This is an advanced transient flow and temperature model. The model handles calculation of

- Pressure/ECD, temperature, and pit volume vs. time while drilling, circulating, and displacements, including flow of cuttings.
- Transient well pressure and flow vs. time during surge and swab; handling details of individual stands as well as tripping the whole string in or out.
- Equivalent Static Density and temperature vs. time during static periods, e.g. flow checks, connections, and other pump stops. Takes into account multiple fluids.
- Transient pressure and flow vs. time while resuming circulation after static periods.
- The model includes state of art sub-models for frictional pressure loss and fluid density. Pressure and temperature dependence of fluid properties can be taken into account through the input of laboratory data (rheology, density, thermal properties), or by using published correlations on fluid density. The model combines lab and field rheology automatically. With multiple fluids, fluid properties of different fluids are independent.

When developing this model special focus was put on the adaptation to a real time or training environment. New requirements include flexibility and easiness to include any flow combination and direction; calculation speed requirements to be fast and stable enough to model operations in real time and training as well as performing automatic calibration and forward looking modeling. The flow model includes all relevant flow operations and characteristics in one model (single phase drilling, multiple fluids during displacements and cementing and multi-phase flow during well control and MPD/UBD operations).

Details of the flow model are given in ref. 3.The model has been used in design, procedure development and also for real time optimization and follow-up of critical operations; see references 4-9.

Torque/drag. An advanced torque/drag model has been built, see references 10-12. The model is applied for the calculation types:

- Calculate WOB and TOB from surface data.
- Calculate bit torque with input of surface torque or vice versa.
- Back-calculation of friction factor with input of measured surface and bottom hole weights or torques.
- Bit depth correction due to string elasticity, buoyancy, pump rates and pressure.
- Weight and torque effects from stripping rams and other closing devices, like rotating control devices (RCD).

Rate of Penetration, ROP. While drilling a well, the rate of penetration will vary. Some of this variation is due to variations in the formation parameters and some is due to variation in the drilling parameters. The important formation parameters are the compressive strength and the formation pressure. A realistic ROP model has been implemented which allows for using the expected rock properties and formation parameters as basis and input to the modeling, and giving back a very realistic drilling response. With this type of design it is possible to modell realistic trend data for well control training such as "negative drilling break" when entering the cap rock, or a "drilling break" when entering the reservoir with the initiation of a kick scenario.

Topside

The generic topside simulator emulates the drill floor of a modern offshore drilling rig and contains standard generic equipment that can be configured to operate like an actual rig's equipment. The generic drill floor contains drawworks, topdrive, slips, pipe handling machinery, including racker and fingerboard, iron roughneck, manipulator arm, mud bucket, mud pumps, cement pumps, trip tank and trip tank pump.

The generic drill floor's drawworks is an active heave compensation (AHC) model and allows drilling in wave conditions providing up to +/-6 meter actual rig floor movement. Simulations using top mounted compensators are provided on rig specific drill floors.

The surface lineup is highly configurable and include standpipe manifold, choke manifold, kill lines, return lines with valves and pits to enable different flow paths both for flow into the well and returns. The simulator allows pumping different fluids into the well through Kelly line, kill line, on top of riser using the trip tank pump and returns can be taken via normal return line to shaker or diverted overboard or via choke line to mud gas separator and flare/production.

Additonal surface lines, or flow paths, can be added to the simulator to provide additional capabilities. In the MPD module lines were added to provide for return over MPD choke skid and using an additional back-pressure pump to build pressure in the well. Similarly, other lines, eg. booster lines or lines for continuous circulation equipment can be added and flow paths changed to accommodate other drillfloor or operational layouts.

The control system of the generic simulator consists of two Cyber chairs, one for the driller and one for the assistant driller as well as virtual BOP and choke panels and loggers. The chairs are similar in operation to common manufacturer's Drilling Control Systems and can be customized to emulate specific rig's or specific manufacturers control systems.

The interface between the two simulators is generic and can be extended to allow simulation of other equipment, processes and tools. The topside simulator can be exchanged for another more advanced instance, eg. replicating the control system, drillfloor and equipment of a specific rig or adding other control systems and equipment entirely, eg. simulating coil tubing drilling equipment

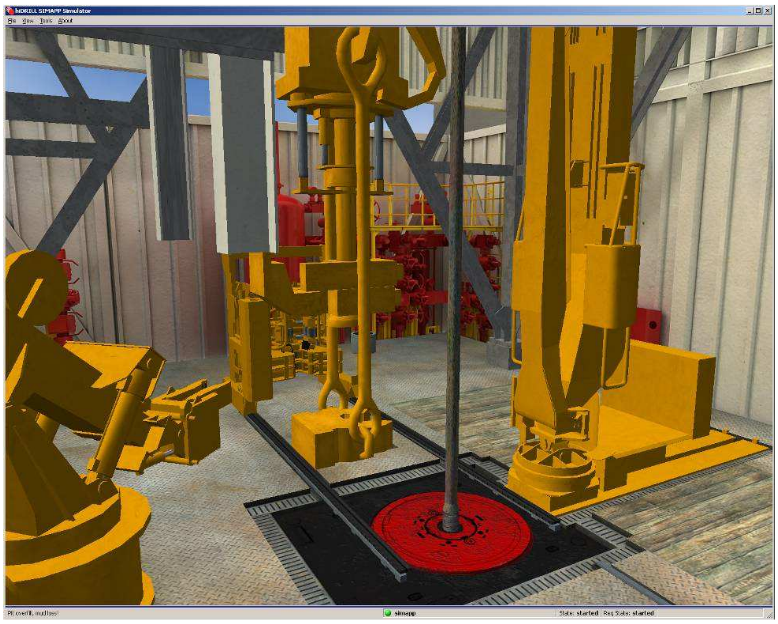


Figure 2 Typical drillfloor layout

Objectives and Focus

The main objective for the development of the new training simulator has been to achieve safer and more cost-effective drilling operations through simulator training ***on the actual well to be drilled*** **and with a** ***topside configuration*** **that responds with pressures and flow rates as expected for the actual rig.**

Focus in the training simulator has been to improve the ability for the drilling team to identify potential serious problems early and learn to rectify the operations accordingly. Learning from technical side track episodes will have high priority. This will contribute to the improvement of:

- Efficiency, quality and safety through better process understanding, skills and team work
- Company's ability to implement new technology
- Exchange of experience between drilling crews
- Implementation of company strategy

The following elements were necessary to reach the objectives:

- Implement a drilling process model; Integrated Drilling Simulator (IDS); which represents the true physics and is dynamic
- Integration with Mechanical Earth Model & related data
- 3D Visualization combined with virtual and/or augmented reality
- Link to machine control simulator
- Link to company drilling database
- Very realistic training scenarios

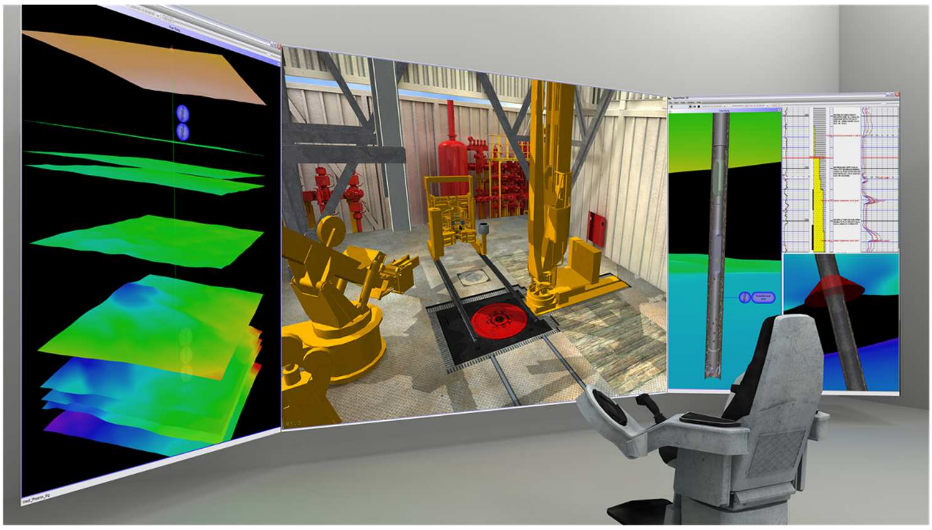


Figure 3 Typical Simulator setup

Benefits with the Training Simulator:

The Simulator contains a dynamic model that models the time development of the drilling, and also takes into account dynamic effects like inertia, acceleration and retardation, effects of temperature and pressure changes downhole on flow, string, well stability and pore pressures. This enables:

- Simulation of fingerprinting; flowback effect in deep water wells. Possible to train on interpretations of fingerprinting and differentiating between influx and no influx.
- Simulation of dynamic surge & swab effects while running pipes and completions. This makes it possible to train on safe tripping and connection procedures.
- Dynamic kick development is modeled. This is realistic compared to simplified static models and enable also to train on effects of gas in riser and how this will develop and can be handled.
- Simulates dynamic developments of pressure losses in choke & kill lines. Enables to train on safe procedures and realistic responses while doing well control.
- Simulation of effects of dynamic temperature changes on mud properties and cuttings transport. Enables to train on effects of low mud temperatures at the mudline and how to improve cuttings transport in deep and cold risers.
- Realistic feedback on ROP and WOB

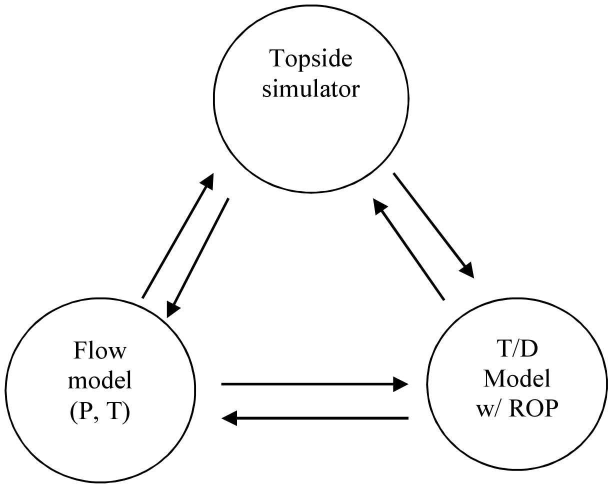
The dynamic training simulator will enable realistic training on the following:

- Drilling and tripping operations
- Stripping operations
- Connections
- Multi fluid operations
- Well control (kick and losses)
- TTRD (Through Tubing Rotary Drilling)
- MPD (Managed Pressure Drilling)
- HPHT (High Pressure High Temperature)
- ERD (Extended Reach Drilling)

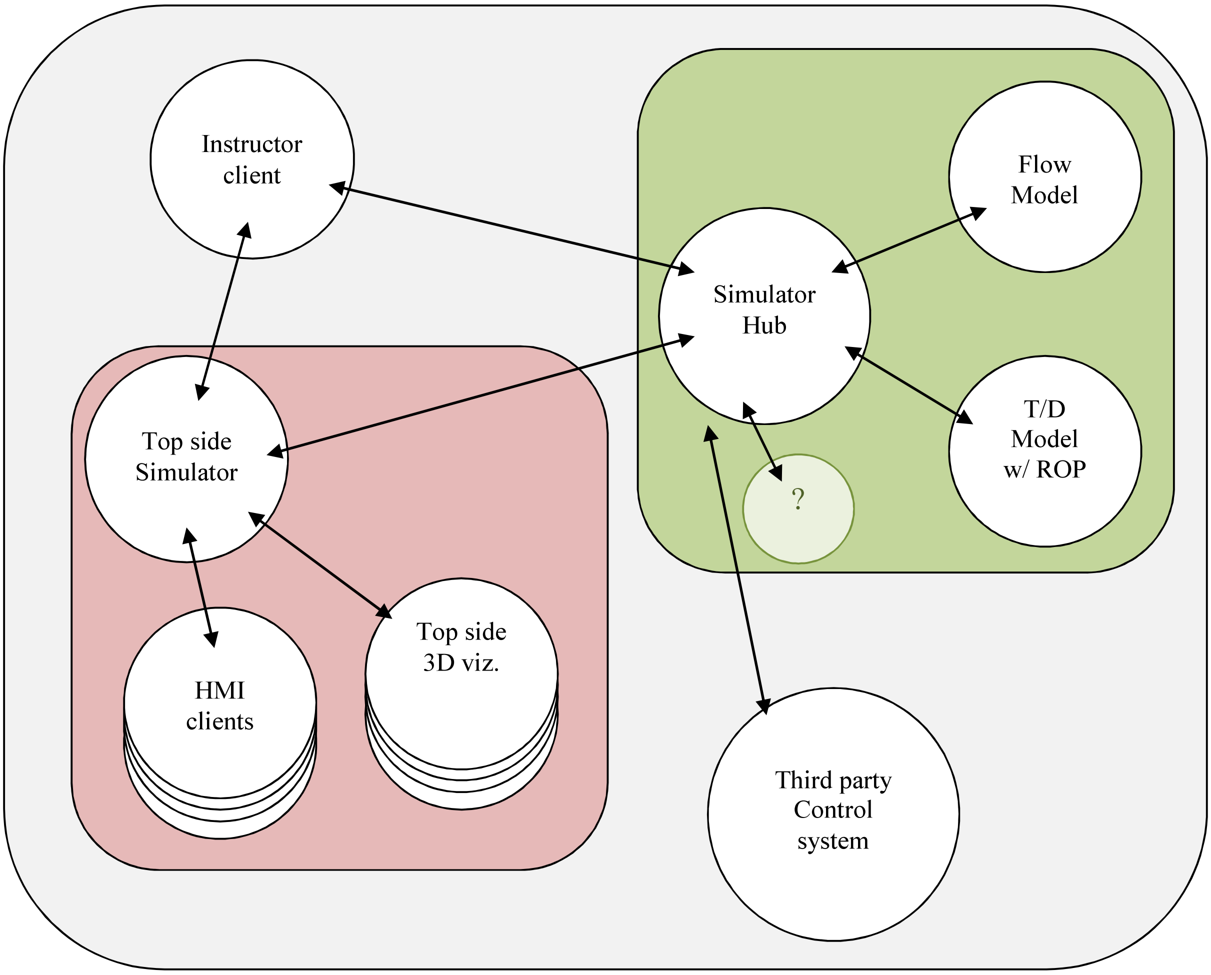
This training simulator can easily be modified for the Well systems used on specific rigs or on other assets.

Simulator Infrastructure

The simulator contains of a cluster of computers working together to give a realistic behavior. The top side and the down hole are two separate simulators integrated into one simulator. As described earlier, the down hole simulator consist of several models, a flow model for the hydraulics and temperature modeling and a torque and drag model linked to an ROP model. The torque and drag model is closely integrated with the top side simulator to give realistic responses on hook load, rotation and block movement. The flow model gets flow rate, density, temperature and a fluid identifier for each of the topside lines (kelly line, kill line etc.) from the top side simulator. The close interaction between the different modules (see figure below) and the configurable setup of well and surface systems give a realistic response.

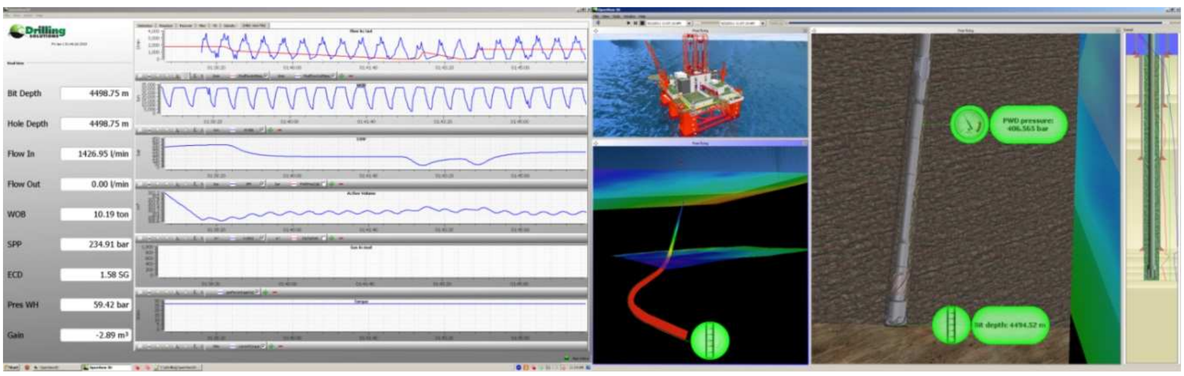


All modules are tied together with the Instructor client application; see figure below. This application is used to configure the well, setting up the scenarios, starting the simulations and trigging of events. All modules are synchronized by a common clock which is controlled by the Instructor client. By shortening the time steps in the clock it is possible to run the simulator in real time and faster than real time (2, 4, 8 and 10 times real time).



When starting up the Simulator the instructor clients sends a wake up signal to the distributed system and starts the different clients in the simulator. As seen on the drawing above, the different top side modules communicate directly to the top side simulator which again communicates with the down hole simulator. By using a modular client server architecture it is possible to run as many HMI clients and 3D clients as wanted. The same applies to the Simulator hub where the down hole models run; here it possible to expand with more models if needed. This is for example done in the generic MPD module, where a set point generator flow model is used to control the MPD choke. It is also possible to connect a third party control system to the infrastructure. In this case the MPD service company connects their own choke control system to the Simulator.

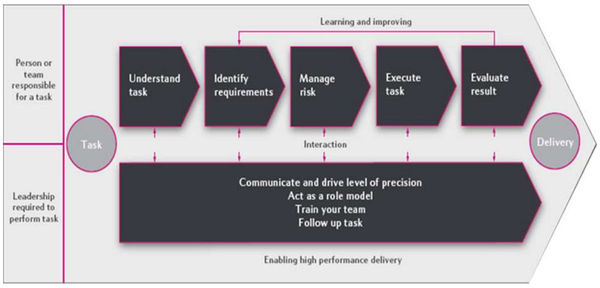
Visualization of the down hole data is done by plotting tool and bottom hole 3D visualization tool (see below).



At the same time it is possible to allow other data visualization tools to connect to the simulator to allow the drilling crews to have the same visualization as they are familiar with from the rig.

Training Philosophy

The Operator's ambition is to raise company-wide performance and thus reduce the likelihood of loss due to deficient quality and precision in its activities. The objectives are thus improved risk handling, more effective work processes and continued development of leadership skills in order to provide the foundations for a value-based performance culture. To ensure quality in all aspects of its activities, a generic work form for use in all delivery processes has been introduced in the oil company.



The Compliance and Leadership model describes a generic work process on how the Operator plan, execute and evaluate its deliveries. The model applies to any task and is the way the Operator work – also when performing training at the Drilling Simulator. With the application of this model during Drilling Simulator training one achieve:

- Focus on the work process with the verification of procedures, including risk assessment and control (Task, Risk, Requirements, Execution and Delivery).
- An enhanced understanding of down-hole effects and competence in the handling of critical operations (On the job training).
- Teams with communication skills, safety culture and attitude as required for safe and efficient operations (Crew Resource Management).

The team's competence and ability to plan and execute tasks is vital to the success in the Operator's Drilling and Well operations. Hence, the purpose of the Drilling Simulator is to provide realistic team training on common and critical drilling and well operations in order to verify and build competence, and in this way ensure safe and efficient operations according to the Compliance and Leadership model.

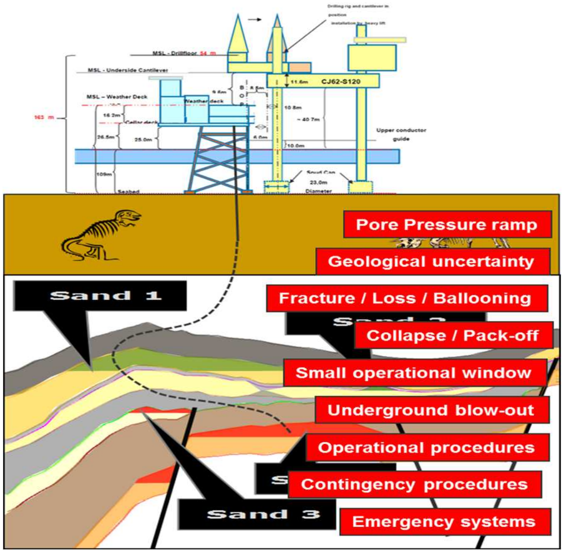
In practical terms, the planning and execution of Drilling Simulator training is handled as follows for the Operator's D&W projects:

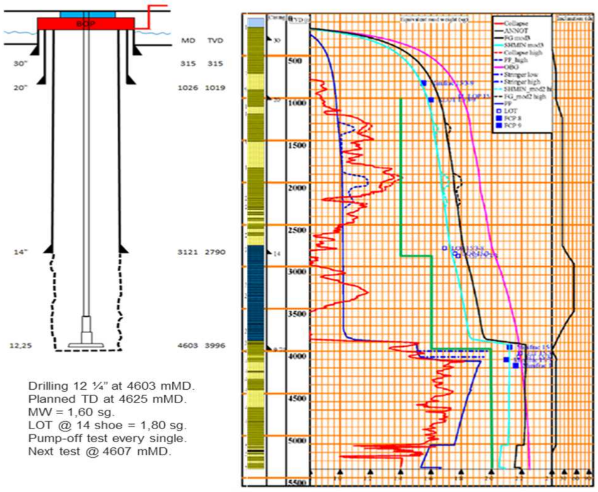
- The D&W project provides input on plans and challenges as defined in their risk register.
- The provided well and formation data are loaded into the Simulator.
- Scenarios for training are dicussed and matured based on D&W project needs and the Drilling Simulator functionalities.
- Training cases are prepared with historic trend data such that the team should be able to detect, react and recover from pre-defined problems with the use of project specific procedures.
- In order to ensure Hands-on training one crew is drilled at the time. The team consist of:
    - Driller
    - Assistant Driller
    - Toolpusher
    - Drilling Supervisor
    - Drilling Engineer
    - Subcontractors (Data operator, Mud Engineer, Cementer, MWD/LWD Engineer, etc)

HPHT Well Specific Training

The preparation of HPHT well specific simulator training starts with a meeting where the D&W project present their task and project specific challenges based on their well design and risk register. These challenges are evaluated and discussed with the simulator team in order to align on goals for the simulator training. Typical HPHT scenarios are reviewed and training cases are selected based on the projects requirements and the simulator capability, including the need for operator induced events/effect during the training sessions. Some of the common HTHP scenarios for training are related to:

- Drilling into a pore pressure ramp with the focus on volume control and the challenges related to Equivalent Static Density (ESD) versus Equvalent Circulating Density (ECD) with well specific Pressure and Temperature induced effects.
- Best Practice drilling and connection procedures when performing drilling operations within a small operational window (pore pressure/fracture pressure), including the effect of minimum horizontal stress once a fracture has been induced.
- Geological uncertainties with wellbore instability, kick, loss and ballooning effects, and the identification and handling of these according to project specific HPHT procedures.
- Different types of kick scenarios including the detection and handling of these according to basic and more advanced well control procedures (Driller's method, Volumetric, Bullheading, Top kill, etc).





The simulator day normally comprises three different scenarios based on well design and formation data from the D&W project. The drilling teams are then challenged according to events and procedures as specified by the D&W project in order to meet the training goals. In this respect the intension with the training is to apply competence on "real" events where the general experience may be low or the downside to the planned operation is high.

A vital factor to the success of this team training is an outspoken and enthusiastic instructor who is able to promote an open dialogue within the team. He is also the one who sets the stage by presenting the case with the status of the well and historic trend data during a driller's handover. In this way it is possible to provide sufficient information for the team to detect, react and recover from a pre-defined scenario within a 1 to 2 hours session on the simulator.

Depending on how the teams handle the cases prepared, time-out is called for during the events in order to discuss solutions and actions performed in light of the procedures available. These time-outs are vital both in order to ensure the individuals understanding of wellbore effects based on actions peformed, and for the verification of the procedures prepared by the office engineering team. Furthermore, this open dialogue promotes the communication skills within the team such that individuals learn to appreciate and use the collective knowledge and competence within the team. As such the Drilling Simulator is often also refered to as the "Communication Simulator".

MPD Training

MPD is a very good case for the training simulator because of the complexity of the operation. Extra teams of operators are brought in to operate extra equipment, like MPD chokes, back-pressure pump, rotating control head, snubbing equipment, and extra stripper rams. Good communication within teams and between different teams, and good understanding of roles and responsibilities are essential for the success of the operation.

The training sessions focused on the normal drilling crew and the MPD team. It covered normal operations like drilling and displacement, as well as different unwanted situations. The instructor may for example trigger kick situations by increasing reservoir pressure to higher then well pressure, and then the simulator will calculate the resonponse to influx and gas or oil being transported up the annulus. The drilling crew will than be able to go to red zone (i.e. close rig annular), and continue with either normal circulation of kick to surface or bullheading. Unwanted situations also include loss to formation, leakages, drill string washout, and stuck pipe.

The experience from training is that it was a very useful refresher both on understanding of how to detect and handle various scenarios in the well, and on the communication within and among teams that is so important during such tight margin operations. Note that this is important both for the normal drilling crew, and for the extra MPD related operators.

Testing MPD Control Systems

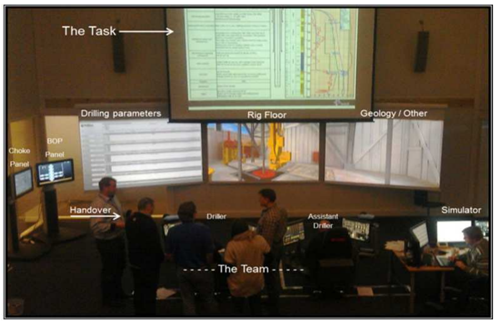
A very useful spin-off from training is that it gives a good and realistic test of the advanced and complex computer systems, and the data flow between various systems. When using the simulator for MPD first time, the well was in many ways very different from earlier wells. It was a long TTRD well with slim geometry and high frictional pressure loss. It turned out that this challenged the dynamic flow model more than expected, and there was accordingly a good opportunity for improving and retesting the model before going offshore. This probably saved several days of rig time and reduced risk related to last minute software update.

Future Possibilities with the Simulator

A fully integrated simulator (topside and downhole) open new possibilities related to use.

1. Education/learning; An integrated simulator will give students a much better understanding of the drilling process being able to see topside equipment interacting with downhole. Dynamic effects can be demonstrated and students can use the Simulator as a tool for doing exercises.
2. Customize for Drill Well on Paper Exercises; by simplifying the topside interaction and using the fast forward mechanism the simulator can be a useful tool in discussion and design verification processes.
3. New Drilling Methods/Concepts; Control systems for new drilling concepts can be connected to the topside and the dowhole simulator will give realistic feedback to the controls system. This means that both control system functionalities and process related issues can be tested and verified as a step in the qualification for new concepts or control systems.
4. Seamless integration with RealTime operation; It is possible to run the downhole simulator with real-time data from an ongoing operation and calibrate the models automatically. When something unexpected occurs in the operation it is then possible to use a well specific calibrated downhole simulator for what-if scenarios in the simulator.

Experiences from Training



The well construction process comprises a number of tasks and challenges from the planning stage via the execution phase to the delivery of the final product. In many ways this work process is clear, but there will always be an uncertainty with regards to our ability to handle these tasks during the operational phase. Plans are communicated in programs and procedures with the focus on limitations and risks for the different sub-operations. It is important to ensure that this information is clear and understood as intended, and that the risks listed on a piece of paper can be addressed with the competence as required in order to deliver a safe product within the time and cost planned.

With the application of the Drilling Simulator the Operator now has an additional tool to ensure quality in its operations by playing out different outcomes of the sub-operations on the simulator. By preparing well specific events on the simulator the drilling teams may gain experience with possible project challenges prior to start of operations, which again has resulted in enhanced focus during operations. In this way the Operator has registrated the following benefits from the Drilling Simulator training:

- Valuable verification of plans and procedures with "live" interaction between the planning and the operational team.
- Enhanced operational risk assessment and preparation of tasks.
- A better understanding of down-hole effects and limitations.
- A better understanding of key drilling parameters and best practices.
- A better handling of field and well specific challenges.
- Enhanced team execution of critical events and well control situations.
- Realistic application of skills and assessment of competence.
- Verification of emergency systems and procedures.
- Enhanced understanding of the Compliance and Leadership model.

The application of the Compliance and Leadership model through the Drilling Simulator training enables a realistic test of plans prepared, and provides important feedback to the planning team for update of procedures. It can also identify gaps within the team's competence as required for the task at hand. In this way the Simulator training develop teams that are better prepared to execute tasks, handle critical situations and to ensure safe and efficient drilling operations.

Summary and Conclusions

An advanced dynamic training Simulator for drilling has been established. This Simulator has been utilizes for training drilling teams utilizing the novel virtual reality features of the Simulator, and thus creating a close-to-reality training with dynamic feedback from the well. The Simulator has been utilized for training on well specific challenges on a close-to-reality well and rig model. Complex scenarios in high risk wells (HPHT, MPD etc) have been trained on, and have given higher competence as well as enhanced the team's ability to handle pre-defined risks in the planned operations. In addition procedures and new drilling systems / control systems have been tested, utilizing the Simulator as a virtual well laboratory.

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