TECHNOLOGIES TO IMPROVE DRILLING EFFICIENCY AND REDUCE COSTS

A report from OG21's technology group on drilling and intervention (TTA3).

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CONTENT

EXECUTIVE SUMMARY:
REDUCE DRILLING COSTS TO MAINTAIN VALUE CREATION

The OG21 technology group on drilling and intervention (TTA3) has been asked by the OG21 board to identify and describe technology related measures that could reduce drilling and completion costs on the Norwegian Continental Shelf (NCS) significantly over the next 3-5 years.

This report summarizes the data analyses and evaluations made by TTA3, and also provides recommendations for further work as well as for stimulation of technology development and implementation. The analyses and evaluations are based on:

- Publically available data and reports
- Company data provided by study participants
- Consultant data and analyses
- Interviews with industry experts
- Workshops

Cost saving measures have been split into:

- Specific technologies (described in Section 4)
- Other measures (Section 5)

Investment costs on the NCS have increased three-fold since year 2000 and exceeded 200 billion NOK in 2013. Drilling and wells investments contributed to approximately 50% of the total, or more than 100 billion NOK a year. Higher activity explains part of the investments increase, but cost inflation is the major contributor.

With a maturing shelf the average field size and average reserves per well is decreasing. With continued cost increases, more and more well targets will become un-economical to drill, and reserves that previously would have been extracted, may be left in the ground. If costs could be reduced, more wells would become economical resulting in increased recovery and value creation for companies and society.

Drilling costs are primarily a product of day rates for rigs and services and the time used to drill a well. Technologies' main scope for cost reductions is to reduce time, and we discuss in this report technologies that would make drilling more time efficient and less prone to down-time. Day rates for rigs and services is mainly driven by the market, but we also discuss some technology related topics that may contribute to a more efficient market that would reduce day rates.

EXECUTIVE SUMMARY:
TECHNOLOGIES MAY REDUCE COSTS BY 20%

In the report we list examples of technologies with a potential to reduce costs on the NCS over a 3-5 years perspective. The list of technologies serve the purpose of demonstrating that new technologies may go a long way in reducing costs on the NCS, but the list is neither exhaustive nor exclusive. Identified technologies are:

- Managed pressure drilling
- Expandable tubular technology
- High speed well communication
- Steerable drilling liner
- Automation and autonomous systems
- Plug and abandonment (P&A)*

As the NCS is maturing, reservoirs become more complicated to drill due to factors such as deeper fields, longer wells, high pressure high temperature (HPHT) and depleted reservoirs / heterogeneous pressure regimes. Providing better control with bottom hole pressure is the key aspect with many of the listed technologies. In addition to adding value for challenging and problematic wells, such technologies might also increase rate of penetration (ROP) and reduce non productive time (NPT) for less complicated wells.

Each of the listed technologies has the potential to create considerable value on the NCS through increased drilling efficiency. We believe that utilizing a host of technologies such as the listed ones, could reduce the average construction time for wells by 20%, and correspondingly save investment costs of up to 20 billion NOK annually on the NCS. Value creation through increased recovery and drilling of wells problematic to drill with traditional technologies, comes in addition.

*P&A has until now not drawn huge investments, but there are significant P&A liabilities for historic and future wells that may bind up capital, human resources and rigs, unless new methods and technologies are introduced.

EXECUTIVE SUMMARY:
NON-TECHNOLOGY MEASURES HAVE A SIMILAR POTENTIAL

There is a cost saving potential in a number of other areas. Some are related to how technologies are applied and some are of a more commercial character.

On the use of technologies, the study group believes the largest cost saving potentials are related to:

- Contract structure - contracts are to a large extent time based and lack incentives for time efficiency. Risk and reward mechanisms discourage early implementation of new time-efficient technologies.
- Work culture – a culture has evolved with little concern for time use in the planning for and execution of operations.
- Work processes and maintenance.

Other areas with cost saving potential are well covered in the Rig Committee's report from 2012. The study group believes that the analyses, observations and recommendations made by the Rig Committee are still valid. We would especially re-emphasize the importance of the following:

- Harmonisation of regulations and standards across borders – Norway specific requirements drive costs by (i) limiting the rig market, and (ii) costly upgrades of rigs being brought into Norway.
- Contracts – (i) standard contracts could reduce bureaucracy and costs, (ii) rig consortiums makes it easier for smaller operators to secure rigs at reasonable rates by providing longer time horizons for rig owners, (iii) longer contracts to compensate for costly upgrades of rigs taken into Norway.
- Specialized rigs («fit for purpose» rigs) – lack of specialized rigs leads to too heavy and expensive rigs being used for simple wells.

The study group has not quantified the saved costs by addressing the above topics, but we believe the cost saving potential is considerable and probably of the same magnitude as the potential related to technologies.

EXECUTIVE SUMMARY - RECOMMENDATIONS

What the industry should do:

- Technologies identified in the report improve value creation as well as safety and predictability of drilling operations. Parties involved in drilling operations should come together and discuss barriers to implementation and measures to reduce such.
- Oil companies should use information in the report to develop business and technology strategies.
- Oil companies should influence rig owners and service companies to consider how the report's information could be used to increase competetiveness.
- Rig owners should consider how their fleet could accommodate the use of promising technologies described in the report.
- Oil companies should take the lead to evaluate how drilling contracts could better share risks and rewards, such that incentives are provided for implementation of promising efficiency improving technologies.
- Oil companies should evaluate how drilling operations could be made more efficient through better coordination between the parties involved.
- Parties involved in drilling operations must ensure that competence is developed to harvest the full potential of new technologies and combination of technologies.
- Time efficiency and performance culture should receive increased attention at all organizational levels.

What the authorities should do:

- The authorities should continue the support of new technology development, and identify ways to better stimulate piloting and first use of new technologies.
- Authorities and industry should stimulate and fund development and testing of new, innovative methods and technologies for safe and cost-efficient P&A (including slot recovery).
- Authorities and industry should continue efforts to create a well-functioning, open rig market, by harmonizing requirements across borders.
- Authorities should ensure that regulations are kept fit for purpose, continue the practice of having functional rather than specific requirements, and be wary of promoting specific technical solutions through references in regulations and guidelines.

What OG21 should do:

- Communicate observations and recommendations from the report to authorities and the industry.
- Facilitate a workshop where technology providers, rig companies and oil companies discuss cost saving technologies, barriers to implementation and actions.
- Work with the major oil companies on the NCS to identify and promote potential field candidates to test out new technologies.

SECTION 2

1. Executive summary
2. Study task, scope and boundaries
3. NCS cost picture and main cost drivers
4. Technology related measures with large cost saving potential
5. Other measures with cost saving potential
6. Recommendations

STUDY TASK, SCOPE AND BOUNDARIES

OG21 has its mandate from the Norwegian Ministry of Petroleum and Energy to develop and assist in implementing a national petroleum technology strategy for Norway.

The OG21 Board has challenged its technology group on Drilling and Intervention (TTA3) to identify and evaluate technology related opportunities that could significantly reduce costs on the NCS over the next 3-5 years.

This report summarizes the work performed by a study group consisting of members from the TTA3 group and OG21's secretariat:

- Sigmund Stokka, IRIS
- Dag Breivik, OMV
- Halvor Kjørholt, Statoil
- Martha Roedbro / Rik de Bruijn, Shell
- Johan Kværneland, Total
- Morten Perander, ENI
- Øyvind Salvesen, Research Council of Norway
- Gunnar H. Lille, OG21 secretariat

- Scope:
  - Technologies and how technologies fit into work processes
  - Drilling and well technologies
    - Hardware and software
    - Topside, subsea and sub-surface
    - Incremental improvement as well as innovative solutions
    - Sub-surface knowledge and information
  - Integrated operations/ technologies to improve work processes and work organization
- Outside scope:
  - Reduction of costs through reduction of activity level
  - Details of drilling contracts

SECTION 3

1. Executive summary
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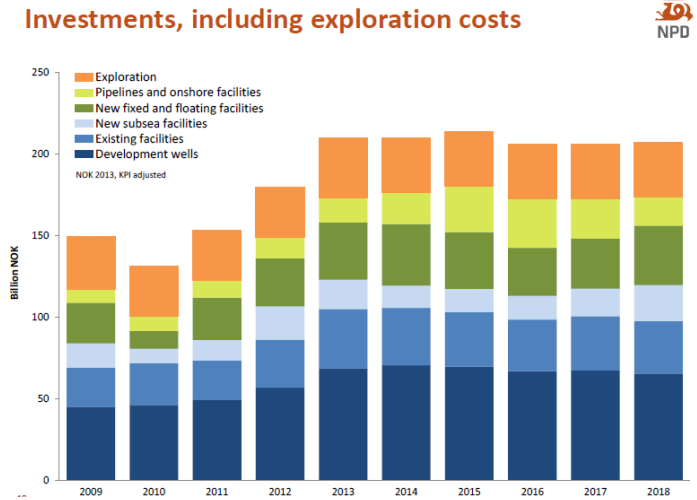
200 BILLION NOK INVESTED ANNUALLY ON THE NCS – DRILLING AND WELLS HALF OF THIS

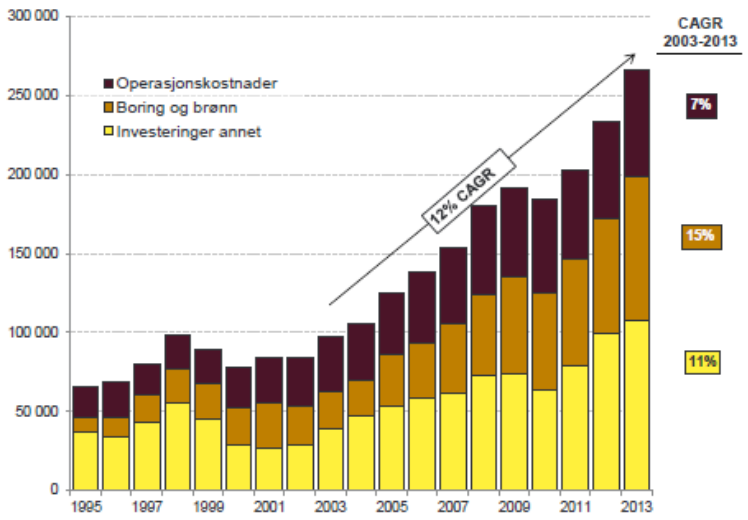
Investment costs on the NCS exceeded 200 billion NOK in 2013.

Drilling of development wells and exploration wells represents approximately half of the investments on the NCS, ~100 billion NOK a year.

The figure bottom right shows the NCS investment development since 1995. Investments in drilling and wells increased by 15% per year on the average in the period 2003-13, which is considerably higher than the average increase for operating costs (7% p.a.) and other investment costs (11% p.a.).

The increase in investments can partly be explained by an activity increase, and partly by cost increases.





Sources: NPD, Rystad Energy

INVESTMENT INCREASES CAUSED BY ACTIVITY INCREASE AND COST INFLATION

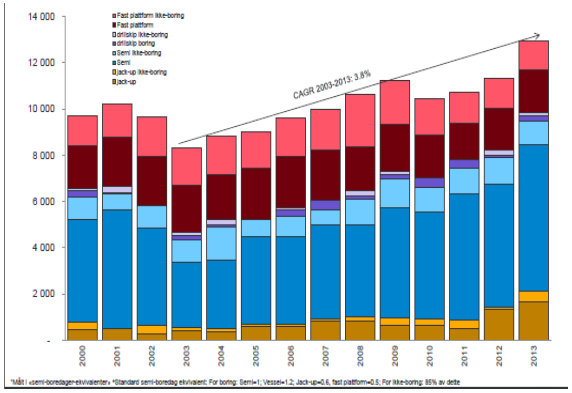
The considerable increase in investments for drilling and wells can partly be explained by an average annual activity increase of 3.8% in the period (figure top right).

The activity level varies however significantly between types of installations. Drilling from semi-subs and jack-ups has annually increased by an average of 10% and 12% respectively, whereas drilling from fixed platforms has slightly declined over the period 2003-13.

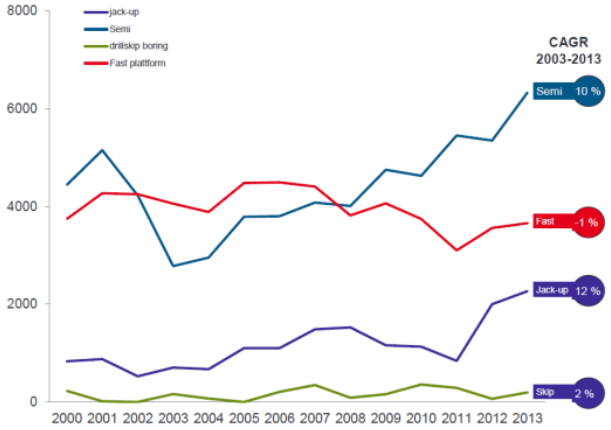
The drilling activity increase for mobile units as compared to the stagnation for fixed platforms can be explained by:

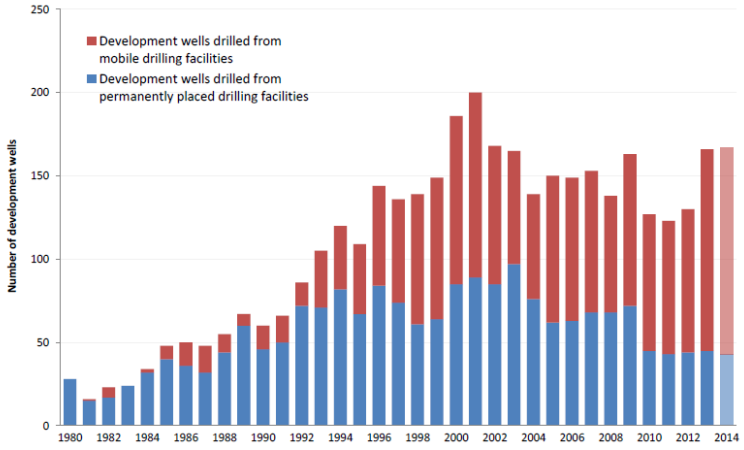
- Lack of drilling slots on fixed platforms
- Increasing number of drilling targets beyond reach from fixed platforms
- Significant increase in exploration drilling (16% CAGR 2003-13)

Rig days w/activities for all drilling units on the NCS



Rig days all drilling units NCS - # days w/activities





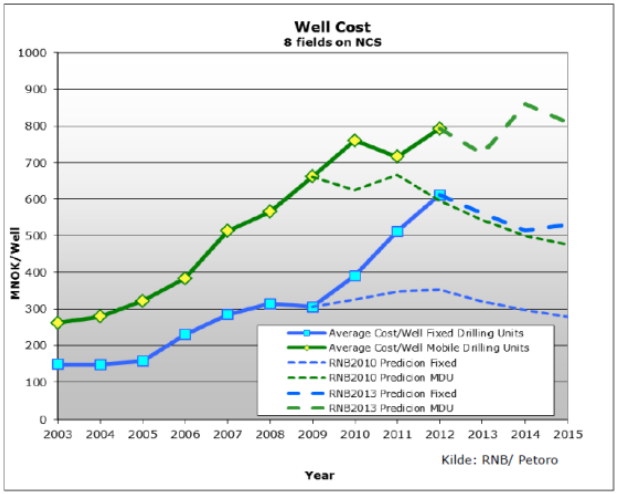
Sources: NPD, Rystad Energy

INCREASED USE OF MODUs, DAY RATE INCREASES, AND DECLINING DRILLING EFFICIENCY DRIVE COSTS

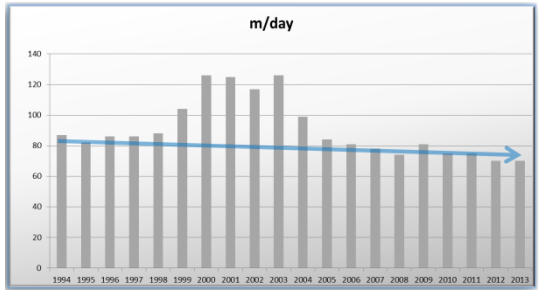
The graph top right shows the well cost development for 8 fields in the Petoro portfolio. Well costs have tripled from MODUs and quadrupled from fixed platforms during the 2003-12 time period. Wells from fixed platforms are still less expensive than from MODUs, but slot capacity constraints on fixed platforms is a significant cost driver.

As shown on the previous page, mobile drilling units have become more and more important on the NCS for meeting the demand for new wells on the NCS. The considerable increase in investments costs for wells on the NCS of 15% annually in the period 2003-13, far exceeding the average annual increase in the activity level of 4% in the period, can therefore be explained by:

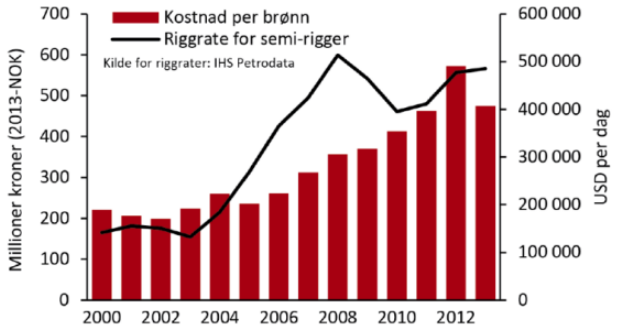
- Increased use of MODUs for wells which could have been drilled with less costs from fixed installations, were it not for the lack of slot capacity.
- Rate increases for rigs and services.
- Efficiency decline in drilling operations.



Drilling efficiency



- Average costs for production wells



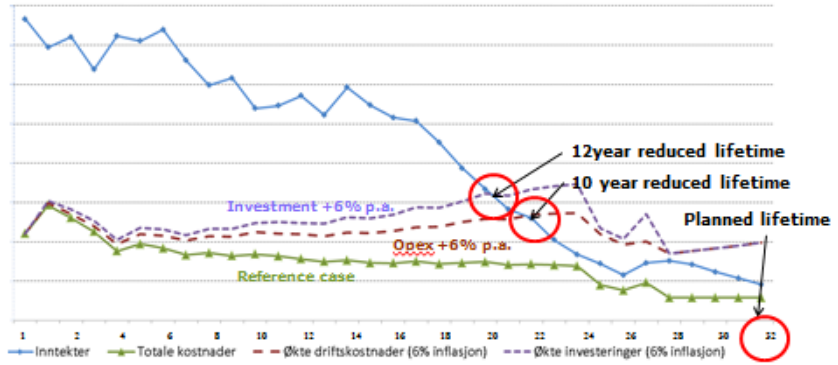
Sources: NPD, Statoil, Petoro

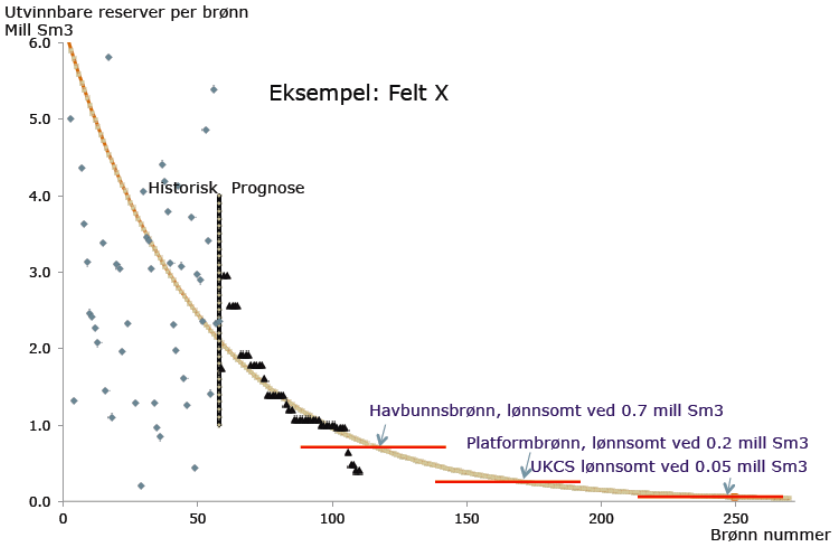
COST INFLATION DETERIORATE VALUE

The graph top right shows the potential effect of cost inflation on a Petoro field case. A cost increase of 6% in either investments or OPEX would reduce the lifetime of the field by 10-12 years.

As the NCS is maturing, the average field size as well as the average reserves per well decreases. The graph bottom right illustrates the latter for a field in the Petoro portfolio. The graph also shows the economical threshold value for subsea wells and platform wells. On the NCS the trend is towards more subsea wells, which have a higher economical threshold than platform wells.

Finding ways to drill wells, especially subsea wells, cheaper, is hence crucial for further development of the NCS and for securing high recovery rates on the NCS.





Sources: Petoro

INDUSTRY EXPERTS VIEW – DRILLING OPERATIONS HAVE A WIDE SCOPE FOR EFFICIENCY GAINS

A total of 10 senior industry technology experts have been interviewed as part of this study to identify:

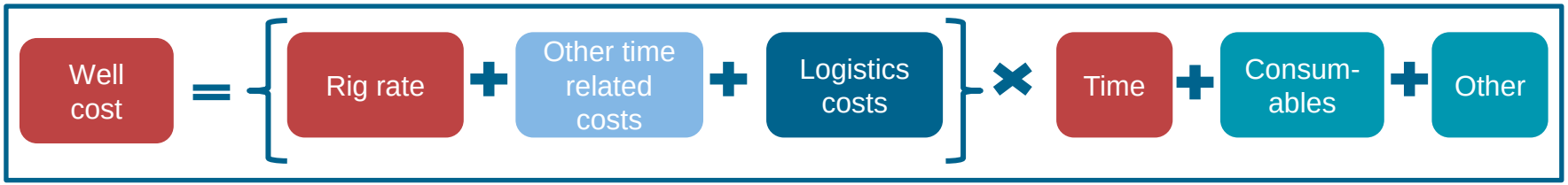
- Areas for efficiency gains and cost reductions
- Technologies and work processes with potential for major efficiency gains

The technology experts represented rig owners, rig management companies and rig service companies.

A summary of the key feedback during the interviews is given in the text box to the right.

- Technologies, technology use and work processes:
  - Some fundamental change opportunities with large impact potential, e.g. MPD
  - Need for more robust technology to reduce Non Productive Time (NPT)
  - Hidden NPT common, e.g. circulating 4x bottom up
  - Norwegian regulations and industry standards drive costs
  - Incremental changes may improve productivity – new tools and methods
  - Need for optimizing maintenance, testing and repair
  - Plug & abandonment with a potential vast investment need
- Organization, competence and culture:
  - Rig intake and utilization can be optimized through cooperation
  - Competence challenges at all levels
  - A culture where «time doesn't matter» has evolved
- High rig rates:
  - Tight market globally for offshore-rigs
  - Norwegian regulations and standards have potentially limited the rig market with negative impact on rig intake and costs
- Contracts and incentives:
  - Time based contracts leads to conservatisms and risk aversion, with a negative impact on productivity

COSTS OF WELLS – TIME USE IS A CRITICAL ELEMENT



The cost for drilling a well can be illustrated by the equation above. Within the frame of this study, with the emphasis on efficient use of technologies to reduce costs, **time use is the element** deserving the most focus.

The rig rate is obviously a fundamental critical cost element which for a specific well operation is dependent upon the availability of suitable rigs, and the market situation for such rigs. Market dynamics is outside the scope of this study, but **specialized, «fit for purpose», rigs** would certainly be a related measure with high cost savings potential.

COMPLICATED PRESSURE REGIMES IS A MAJOR REASON FOR INCREASED TIME USE

Some data suggest that we have become less time efficient when drilling wells on the NCS (figure page 12).

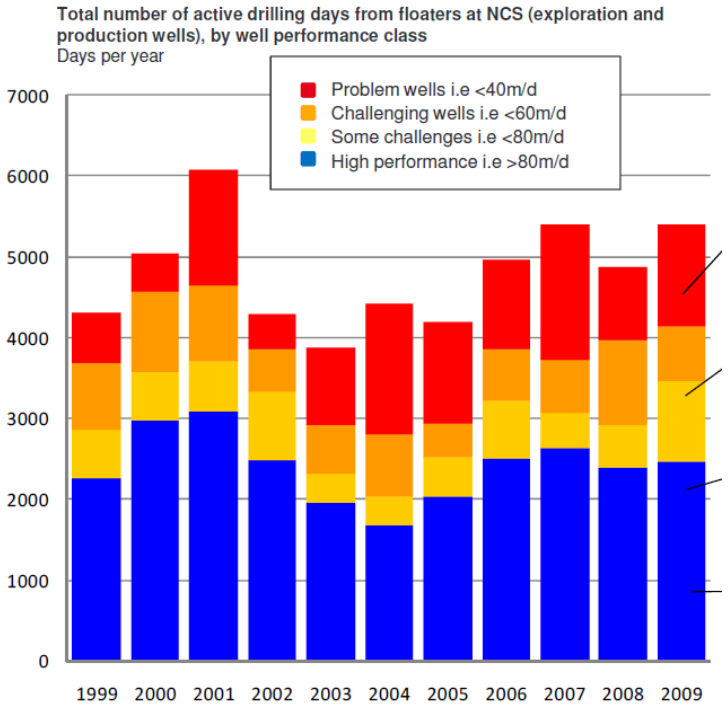
As the NCS is maturing, one would expect that reservoirs become more complicated to drill due to:

- Deeper fields
- Longer wells
- HPHT
- Depleted reservoirs / heterogeneous pressure regimes

The average drilling performance graph on page 12 does not include sidetrack drilling, which constitutes a large portion of wells on the NCS (e.g. 2 out 3 production wells). The performance metric is therefore skewed towards new and more complicated wells, which partly explains the negative trend.

The figure to the right shows that challenging and problem wells represent approximately 40% of all drilling days on the NCS. There is no trend showing a significant change in this proportion over time.

Technologies that provide better control with bottom hole pressure have high time saving potential for challenging and problematic wells, but might also increase ROP and reduce NPT for less complicated wells.

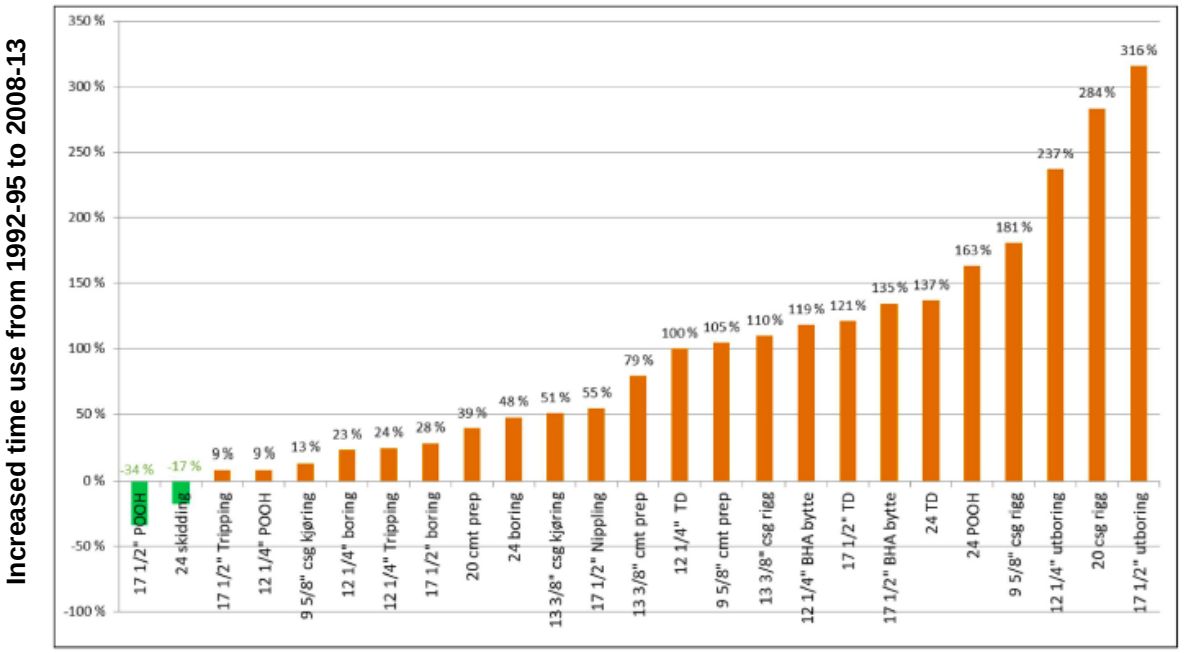


Sources: Rystad Energy, OMR

A GENERAL LOSS OF EFFICIENCY OBSERVED IN THE DRILLING INDUSTRY

As shown on the previous page a high portion of the total drilling time is spent on wells with complicated pressure regimes. Better technologies to control bottom hole pressure would hence have the potential to reduce drilling time and reduce cost.

More complicated reservoirs do however not fully explain the observed loss of drilling efficiency. Data from Petoro given in the graph to the right, shows that for most drilling operation steps, we are less efficient today than 20 years ago. All the operation steps compared are for the same field, same type of wells and before penetrating the reservoir.



Source: Petoro

REDUCING NON-PRODUCTIVE TIME COULD SAVE BILLIONS ANNUALLY

The figure top right shows the average time use in Statoil's driling operations. For MODUs, the unproductive time amounts to 25% of the total time use. This includes waiting on weather (WoW) which typically would be 8-9% of the time.

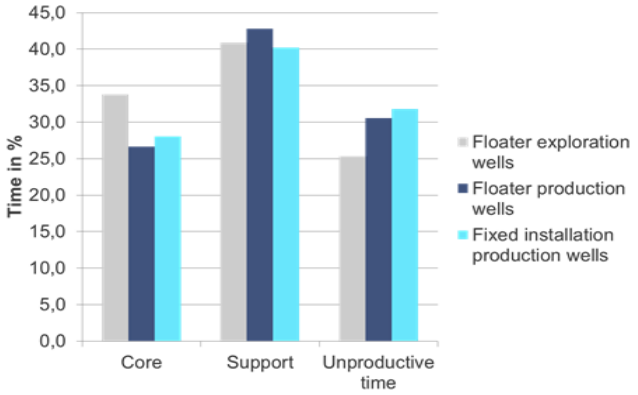
The figure bottom right provides a break-down of time use for floaters on NCS, excluding WoW. On the average, NPT amounts to 16% of the total time use.

Excluding WoW and assuming that all NPT is avoidable, the total costs of NPT on NCS could amount to 15-20 billion NOK/year.

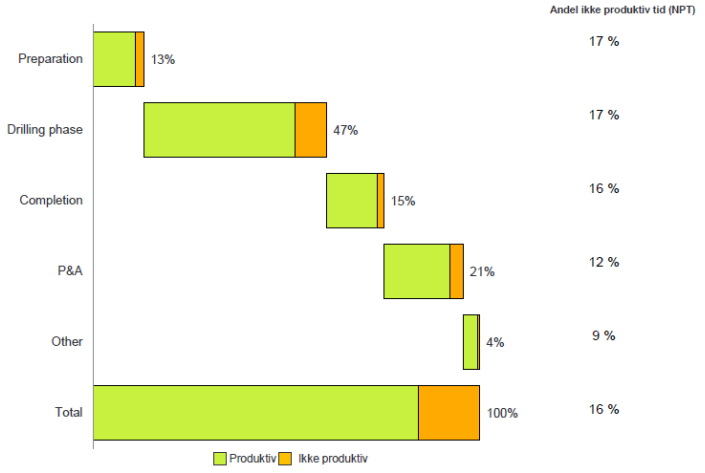
The economical benefits of avoiding trouble are hence considerable. Avoiding NPT in the drilling and completion phases would potentially save around 10 billion NOK per year, based on:

- 220 wells per year
- Average well cost 500 million NOK (page 12)
- Drilling and completion phases 62% of total time use
- NPT 16% of time for drilling and completion phases
- Potential NPT cost savings = 220x0.5x62%x16% ~ 10 billion NOK/yr

In addition to the reported NPT, the interviews revealed a common perception of "hidden NPT" being a substantial contributor to time use. One example is circulating more than needed.



Time use floaters on the NCS
Proportion of total time 2009-2012



Sources: Statoil, Rystad Energy

SECTION 4

1. Executive summary
2. Study task, scope and boundaries
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5. Other measures with cost saving potential
6. Recommendations

TECHNOLOGY RELATED MEASURES WITH LARGE COST SAVING POTENTIAL

Technology related measures with the potential to significantly save costs over the next 3-5 years, have the characteristics:

- Potential for broad application on the NCS
- Market-ready, piloted or close to piloting
- Substantial time-saving potential alone or together with other technologies (typically 5% or more time saving for a well)

Promising technologies with such characteristics have been identified by the study group through workshops and interviews with industry experts. Each measure is discussed over the next pages with details on maturity, applicability for the NCS, and time-efficiency and cost-saving potential. The list of technologies serve the purpose of demonstrating that new technologies may go a long way in reducing costs and increasing value on the NCS, but the list is neither exhaustive nor exclusive. The technologies discussed are:

- Managed pressure drilling
- Expandable tubular technology
- High speed well communication
- Steerable drilling liner
- Automation and autonomous systems
- Plug and abandonment

Other cost saving measures are discussed in Section 5.

MANAGED PRESSURE DRILLING
INTRODUCTION

Managed pressure drilling or managed gradient drilling are general terms used to describe technologies which precisely control the annular pressure profile throughout the wellbore. The technologies can be categorized into single gradient systems, dual gradient system and riser less systems, with further sub-categorization as shown below (Konkraft, 2013). It can be argued that also constant circulation technologies belong under the MPD umbrella. Automated kick and loss detection is closely related to MPD.

Since the introduction of MPD technologies on a Jack Up rig for an exploratory HPHT well in 2003 the methods have been available on the NCS for fixed installations since 2004, but such technologies have not yet been broadly implemented on floaters, in particular not in harsh weather. Statoil has on behalf of Konkraft evaluated the business value of broad implementation of MPD, and the details provided on the topic in this OG21 study is to a large extent based on the Konkraft report and the Statoil/Rystad Energy report supporting it.

Since the Konkraft report was issued, Statoil has successfully tested a MPD-system from a floater on its Troll field on the NCS (see text box to the right).

From Statoil News posted May 20, 2014:

"Statoil Technology Invest portfolio company and offshore technology provider Enhanced Drilling has successfully completed a landmark pilot project with Statoil.

The EC-Drill system from Enhanced Drilling is a managed-pressure-drilling system for use off floating rigs. The pilot, conducted on the Troll Field on the Norwegian Continental Shelf, saw EC-Drill being used in the drilling of three branches of a well, reports Enhanced Drilling in a press release."

Sources: Konkraft/Statoil,

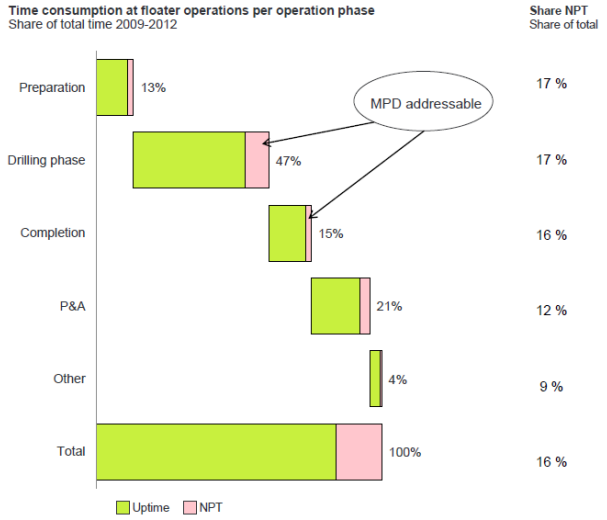
MANAGED PRESSURE DRILLING
VALUE DRIVERS AND APPLICABILITY ON THE NCS

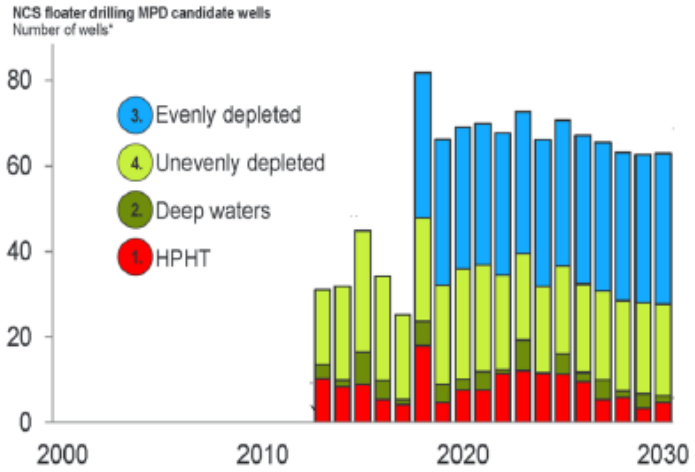
MPD technologies may add value through:

- Reduced costs:
  - Less Non Productive Time (NPT), in particular due to less hole stability, loss- and gain incidents.
  - Fewer casings (more relevant for deep water).
  - Increased ROP (underbalanced conditions, and hence less relevant on the NCS).
- Increased revenue:
  - Drill wells problematic to drill with traditional technology.
  - Accelerated production.
  - Reduce formation damage.
- Reduced risk for safety and environmental accidents

According to the Konkraft/Statoil report, more than 1000 wells from now until 2030 are potential candidates to be drilled with MPD technologies from floaters (figure bottom right). If MPD from floaters is broadly implemented, as much as 45% of the NCS production in 2020 could come from wells drilled with these technologies.

This technology will also have its benefit for mature fields drilling the overburden sections. Disturbed overburden sections from water injections often results in downhole challenges such as side tracks, kicks, and losses. Such wells could suffer from 30-50% downtime for the overburden sections alone. In addition comes the potential downtime drilling the depleted reservoir sections. Implementation of MPD hence has the potential to reduce the NPT extensively. MPD will allow for better sub-surface understanding and adjusting the drilling window as required based on new information.





Sources: Statoil, Rystad Energy

MANAGED PRESSURE DRILLING ON FLOATERS
SUMMARY

Technology description:
- An adaptive drilling process used to more precisely control the annular pressure profile throughout the wellbore.
- Ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly.

Value drivers:
1. Cost reductions through reduced NPT and reduced # of casing sections.
2. Increased revenue by drilling wells problematic to drill with traditional technologies.
3. Increased revenue by accelerated drilling.
4. Reduced safety and environmental risk.

Applicability and limitations on the NCS:
- 1000 potential well candidates until year 2030 which could be drilled favourably with MPD from floaters.
- 45% of NCS production could in 2020 come from MPD drilled wells.
- Early stages of technology demonstration on floaters. Broad implementation on floaters is a challenge.

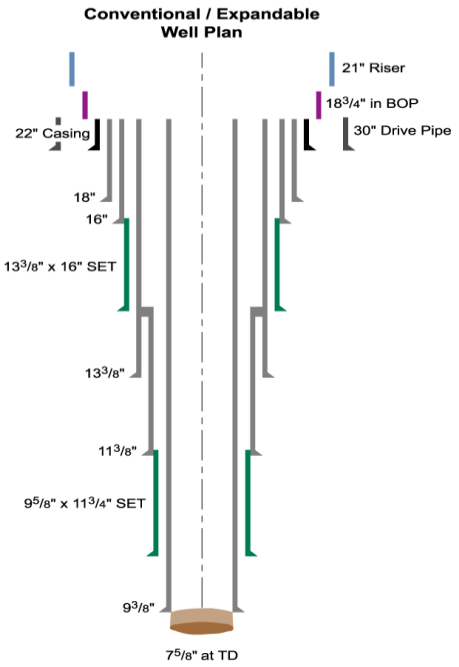
EXPANDABLE TUBULAR TECHNOLOGY - INTRODUCTION

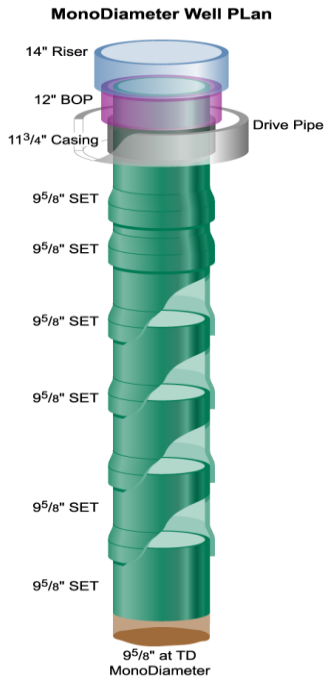
Expandable tubular technology provides capability for selective zonal isolation as contingency against downhole problems. In mono diameter applications it provides opportunities for slimming down well designs. It increases burst and collapse ratings by cladding of lighter casing so that it achieves the same values as for much heavier casing. It can repair corroded tubulars by cladding damaged pipe. This is done through expansion of casings/liner against the previous casing/ liner.

Expandable tubular technology has a number of applications:

- Contingency/repair string (drilling liners and open hole cladding) for selective water shut-off, repairing damaged casing and/or tubing.
- Slimmed down casing schemes (reduced cost of each materials and disposal of drilling waste) increasing burst and collapse ratings by cladding the inside of casing and tubing.
- Monobore wells (one single internal diameter from top to bottom)

Statoil has qualified expandable casing shoe technology for Kvitebjørn and Kristin for one hole section. Shell has successfully installed newly developed mono diameter expandable tubulars in Deepwater Gulf of Mexico wells as well as commercially available SET liner technology.





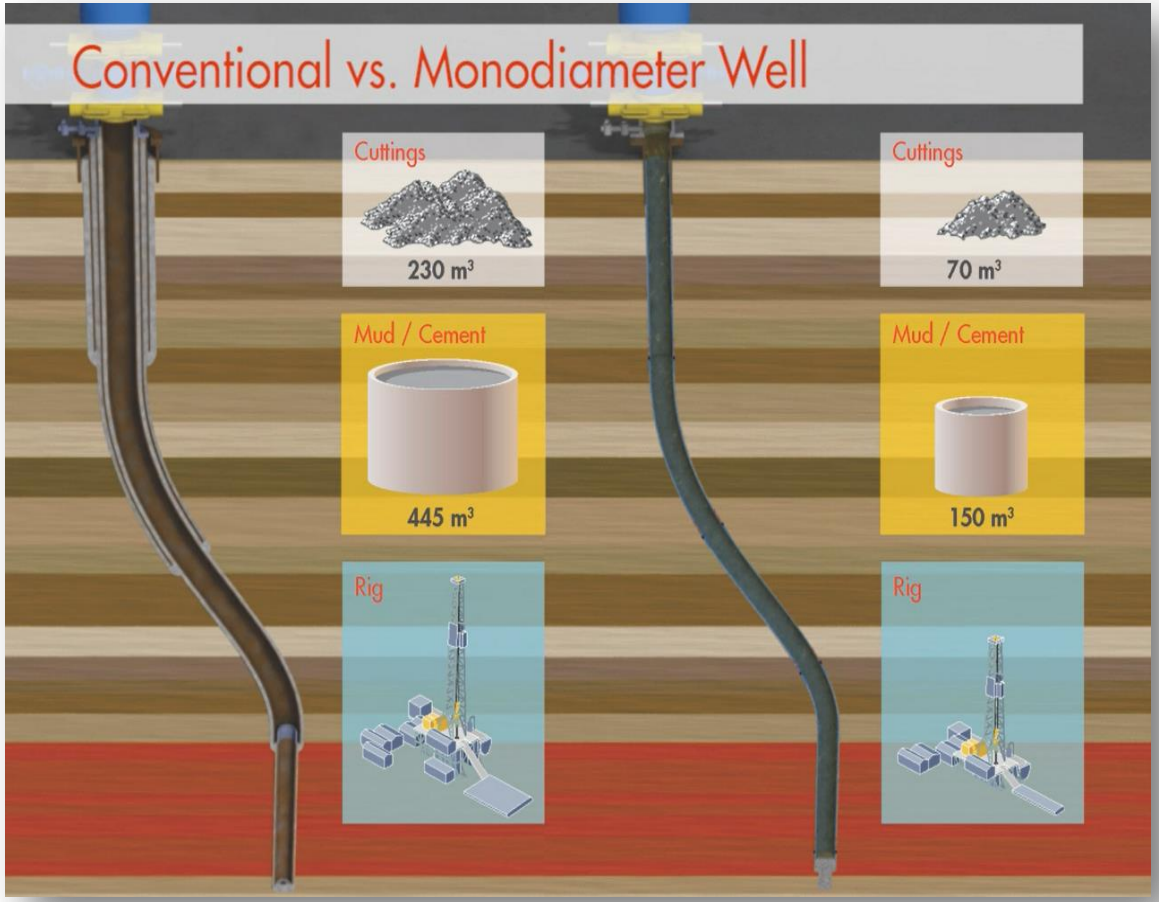
Engineer's point of note:

- Expandables historically have not possessed much collapse resistance themselves and are treated a "Steel Filtercake" and not relied upon for any severe pressure containment. They are suited for isolation of severely depleted sands. Covering them completely by a production liner allows for full cementation of the annulus.

EXPANDABLE TUBULAR TECHNOLOGY-
VALUE DRIVERS AND APPLICABILITY ON THE NCS

Expandable tubular technology applied for one hole section at the time may add value through:

- Reduced costs:
  - Less Non Productive Time (NPT) when running the non-expanded casing with smaller ID through the open-hole section,
  - Fewer casings (more so for deep water),
- Increased revenue:
  - Drilling wells through challenging overburden sections in a more economical way,
  - Drilling wells under depleted reservoir conditions (technology allows for zonal isolation and secures drilling adjusted to ”new” reservoir conditions),
- Reduced risk for safety and environmental accidents
  - Due to stricter manufacturing and installation protocols, expandable technology often has a success ratio at least equal to conventional products.



EXPANDABLE TUBULAR TECHNOLOGY
SUMMARY

Technology description:
- Securing getting the string to planned depth through using relatively small diameter string (pre-expansion) for running through open-hole,
- Reduced swab and surge through use of relatively small diameter string (pre-expansion) for running through the open-hole section,
- Increase probability of casing off hole section successfully.

Value drivers:
- Reduced costs:
  - Less Non Productive Time (NPT) when running the non-expanded casing with smaller ID through the open-hole section,
  - Fewer casings (more so for deep water),
  - Reduced footprint,
- Increased revenue:
  - Drilling wells under depleted reservoir conditions (technology allows for zonal isolation and secures drilling adjusted to ”new” reservoir conditions),
- Reduced risk for safety and environmental accidents
- Improved reputation due to reduced footprint and extension of well life rather than drilling new wells

Applicability and limitations on the NCS:
- Increased capability for casing off ”trouble zones”,
- Increased capability for zonal isolation, repairing damaged casing and/or tubing, and increasing burst and collapse ratings of pre-existing strings.

HIGH SPEED WELL COMMUNICATION
DESCRIPTION OF TECHNOLOGY

- High speed communication with the well and along the well.
- High data transmission rates, typically 60000 bits per second today, allow data to be transferred to surface with minimum time delay.
- Repeaters along the drillstring allow for placing sensors at selected positions along the drillstring.
- Large potential for improved well control, reduced number of sidetracks, reduced well circulation cost and reduced damage from drillstring vibrations.
- One particular technology (Wired Pipe) was successfully tested at Visund and Troll in 2007, and on the Ekofisk Field (Maersk Innovator) in 2013.

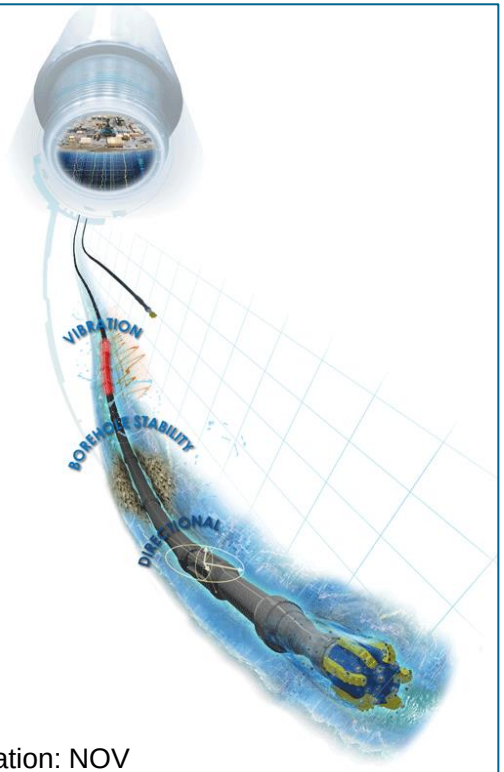


Illustration: NOV

HIGH SPEED WELL COMMUNICATION
VALUE DRIVERS

- Save time:
  - Real-time data save time – less need for circulating the well.
  - Reduce drillstring connection time.
  - Enables better use of of other technologies (e.g. MPD, downhole diagnosis and drilling sequence automation)
- Reduce NPT:
  - Detect cuttings transport problems early to prevent pack off / stuck pipe - avoid drilling problems leading to side tracks
  - Avoid circulating the well when not needed improves wellbore condition
  - Optimise the drilling operation through improved data quality and availability (pressure control, improved drilling parameters, reduced drilstring vibrations)
  - Improve geo-steering implying improved well quality and reduced drilling problems
- Improved safety:
  - Early detection of kick and losses
  - Improved well integrity

HIGH SPEED WELL COMMUNICATION
CHALLENGES AND BARRIERS

- High speed well communication is an enabling technology. To fully reap the potential awards, work processes need to improve.
- The drilling organisation is adapted to receiving delayed data at low data rate, typically 10 bits per second, whereas high speed well communication already today offers 60 000 bits per second.
- Data analysis and presentation need to be developed to benefit from the improved data.
- Few suppliers of the technology in the market today.

HIGH SPEED WELL COMMUNICATION
SUMMARY

Technology description:
- Instrumentation that provides high data transmission rates from the well and along the well -> minimum time delay
- Repeaters along the drillstring allow for placing sensors at selected positions along the drillstring.

Value drivers:
1. Save time:
   - Less need for circulating the well and reduction of drillstring connection time.
   - Enablerof other technologies (e.g. MPD, downhole diagnosis)
2. Reduce NPT by detecting problems early.
3. Improved well integrity and safety by early detection of kicks and losses

Application on the NCS and barriers:
- Technology would be well suited for broad implementation on the NCS. However:
- Current work processes are not set up to take advantage of high speed well communication. Work processes need to improve to fully take advantage of benefits.
- Limited availability in todays market .
- Investment costs hard to justify if only parts of potential value creation is harvested.

STEERABLE DRILLING LINER
VALUE DRIVERS

Steerable drilling liner is a drilling technology where a well section is drilled and lined in the same run. The steering and logging capability is the same as for conventional drilling.

Why replace conventional drilling with Steerable Drilling Liner?

- Save time
  - Remove time between drilling and lining formation
  - No need for reaming, back-reaming and general wellbore conditioning to ensure successful liner installation
- Reduce risk related to formation instability
  - Reduced probability of hole collapse
    - Hydraulic effects *(no tripping in open hole)*
    - Mechanical effects *(low surface rotation, low shock and vibration)*
  - Reduced consequence of hole collapse

Illustration: BakerHughes

THE DEVELOPMENT STEPS TOWARDS A ONE-TRIP STEERABLE DRILLING LINER

- Drill and log a directional well
- Release the liner down-hole
- Exchange inner-string without tripping the liner
- BHA repositioning to drill with minimum stick-out
- Under-reamer instead of reamer-bit
- Set the liner hanger
- Cement the liner w/liner rotation
- Activate and set packer

Current Steerable Drilling Liner (SDL) system

One Trip SDL Phase 1

One Trip SDL Phase 2

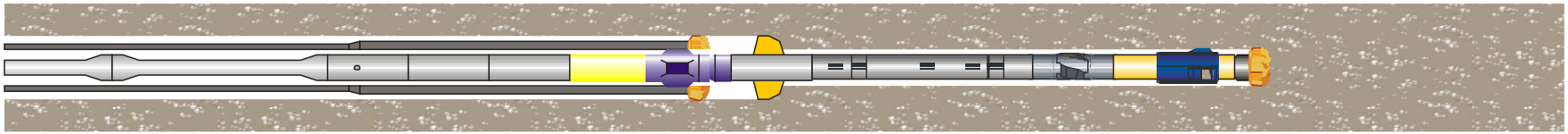
STEERABLE LINER DRILLING
BUSINESS IMPLICATION

- Business case – mainly about time saving (conservative estimate)
  - 2 days saved NPT per section in average.
  - 2 days saved operational time per section in average.
  - Cost saving potential approximately 2.5 % of well cost.
  - Additional value by drilling wells problematic to drill with traditional technologies.

- Market deployment
  - Aim for the one trip steerable liner drilling to be the “new standard”.
  - First version of the system has already been used ten times, expecting a gradual increase until full deployment of the next (one trip) version of the system in 2018.
  - Drillable completion liners (slotted liners) and sand screens are within reach by 2016.

ONE TRIP SDL DRILLING MODES

- Drilling mode



- Reaming mode

- Cementing mode

STEERABLE LINER DRILLING – SUMMARY

Technology description:
- Enables simultaneous drilling and lining.
- In its first version it will be applicable for wells with special drilling challenges. The next version is expected to be relevant for all types of wells.

Value drivers:
- Increased robustness – Less risk for side tracks. Enables drilling of wells that would otherwise be problematic.
- Reduced time – Tripping of liner and need for hole conditioning (reaming, circulation) avoided.

Application at the NCS and limitations :
- Broad applicability on the NCS. The eventual one-trip-system has the potential to become the new standard for drilling of wells.
- First version available in 2011. The one-trip-system expected to be available in 2018.

AUTOMATED/AUTONOMOUS DRILL FLOOR OPERATIONS

INTRODUCTION

The oil and gas industry has currently many solutions in place which rely on mechanised and remotely operated machinery on the rig floor. OG21 identified early the need for whole-solutions for rig floor operations (see project descriptions below), together with downhole feedback algorithms for optimal choice of drilling parameters (see table below). Examples of new, promising technologies are:

Robotic Drilling Systems™ (RDS) - standalone drill floor robots (pipe handler, floor robot, roughneck, multi-size elevator) aiming for autonomous and seamless collaboration between machines (addressing ***Invisible Lost Time***),

Continuous Motion Rig™ – pipe make-up and break-out whilst drill pipe is moving. Relies on ABB Robotics for automated movements of two drilling machines to either "push or pull rope".

From Norwegian Association of Autonomy (NFA) conference Mar 20, 2014:

"It is important that we distinguish between automated and autonomous operations. Automated and remotely operated equipment represents the "traditional approach" that we have taken in the drilling industry for the past decade or so. Every movement of the equipment has to be programmed. With autonomous equipment machines come with self-thinking features."

From same conference (**Robotic Drilling Systems**):

Traditional industrial robots are made to be told HOW TO DO a job and are dependent on a KNOWN SCENARIO.

Drillfloor robots will need to handle a CHANGING SCENARIO and the operator must be able to tell the drillfloor robots WHAT TO DO to limit the need for specific machine competence.

Technology Gap	Time to complete	Costs	Criticality	Market value	Barriers
Closed loop system that optimizes drilling parameters	3-6 years	3-10 MNOK	High	Medium	Reliable downhole data; integration of all drilling systems
Automated/autonomous drilling rig	10-20 years	3,000-6,000 MNOK	High	High	Innovation cost; demonstration

AUTOMATED/AUTONOMOUS DRILL FLOOR OPERATIONS
VALUE DRIVERS AND APPLICABILITY ON THE NCS

A Third Party report from 2010 estimated a cost saving potential for offshore applications of automated/autonomous drill floors of up to 20-30% on time-based operations.

Examples of automated/autonomous drill floor technologies and value added:

- ***Robotic Drilling Systems™***:
  - Introduction of robots to drillfloor operations.
  - Address the up to 20% Invisible Lost Time, which is typically hidden within what we normally classify as Productive Time.
  - Seamless collaboration and handovers between machines may reduce equipment wear.
  - Extra control, ”block programming layer” easy to learn for drilling personnel.
  - Standalone robots make trouble-solving easier (control system installed within each machine communicates into a common server).
  - Autonomous features mean that machines can be left unsupervised.
- ***Continuous Motion Rig™***:
  - Technology with some ”blue sky” features.
  - Challenges the way in which we normally make-up and break-out pipe (drill pipe and liner/casing).
  - Potentially removes connection times (on Norwegian Shelf allegedly between 5 and 40 minutes per connection today) and reduces ”open-hole” times.
  - Increased gross tripping speeds and casing/liner running times (of relevance when drilling for deeper plays and for rigs with dual derrick).
- ***Features in Common***:
  - Get people out of harm’s way (away from the rig floor).
  - Aim for consistency in the way operations are carried out.
  - All-electrical (Robotic Drilling Systems) or nearly all-electrical solution.
  - Challenges the traditional composition of personnal on the rig.

AUTOMATED/ AUTONOMOUS DRILL FLOOR OPERATIONS
SUMMARY

Technology description:
- Robots standardize operations for optimum time savings (tripping, pipe handling, BHA, etc.)
- Flexible and accurate execution with respect to cost and time (higher operational reliability)
- Operation independent of rig crew or day/night shift

Value drivers:
1. Cost efficient drilling operations
   - Faster drill-floor operations through increased speed and less planned/unplanned stops
2. Higher operational reliability
   - Electric design with flexible and accurate motions
3. HSE improvement
   - Move people out of hazard zones
   - Reduces risk of human errors

Application on the NCS and limitations:
- Higher drilling cost
- Challenging wells/area
- Rig rates/cost per meter drilled
- HSE demands
- Competent crew
- Expensive maintenance

PLUG AND ABANDONMENT
NEW METHODS NEEDED TO CONTROL COSTS

The need for permanent plugging of wells is a hugh liability for operators on the NCS. According to P&A Forum, an expert group established by the Norway Oil and Gas Association, more than 6000 wells will have to be permanently plugged and abandoned over the next 40 year. Using today's technologies and methods will require 15 rigs on a continual basis, and incur costs of close to 22 billion NOK a year.

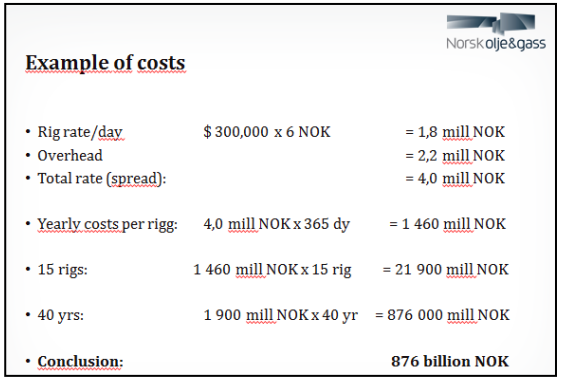
The present value of the P&A liabilities over the next 40 years is around 300 billion NOK (assuming a 7% discount rate).

The required P&A efforts will bind up organizational capacity, and put an additional strain on the rig market.

It is therefore a need for improved methods and technologies that more efficiently will lead to acceptable P&A of wells:

- Technologies that eliminate the use of drilling rigs
- Technologies that reduce the use of drilling rigs
- Improved well design that makes P&A less costly

In the following, the opportunity related to one promising P&A technology is described. Other technologies and methods may have similar benefits.



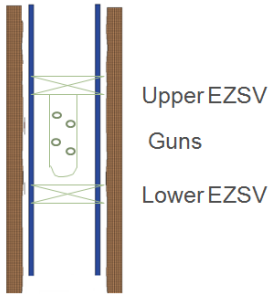
NEW P&A METHODS
EXAMPLE: PERF, WASH AND CEMENT

- The cost for plug and abandonment in NCS is very high. Alternatives to section milling and tools to increase the rig efficiency is required.
- Game changing new technologies is being looked into by most operators in NCS. New methods have to give the same P&A barrier quality as previously.
- The new technology which is being developed include:
  - Perf ,Wash and Cement tool – Objective to perforate & wash perforations and annular space behind casing in preparations for setting abandonment plugs.

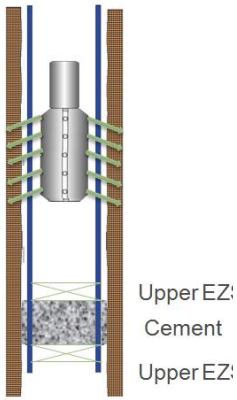
Illustration: HydraWell

NEW P&A TECHNOLOGIES
EXAMPLE: PERF, WASH AND CEMENT

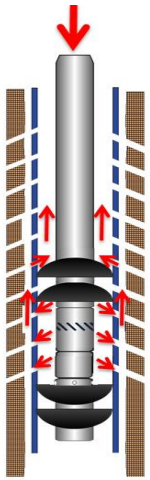
- Objective
  - Reduce rig time during P&A operation. Conventional section milling operation is time consuming and hence costly.
- Method principal
  - Perforate & wash perforations and annular space behind casing in preparations for setting abandonment plugs.

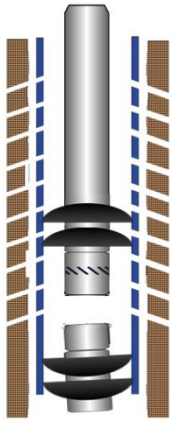


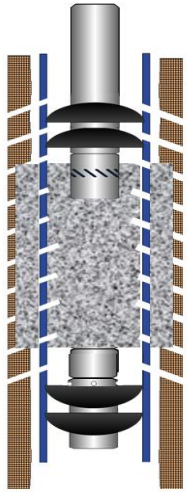
Make fundament (fig 1)



Perforate casing (fig 2)

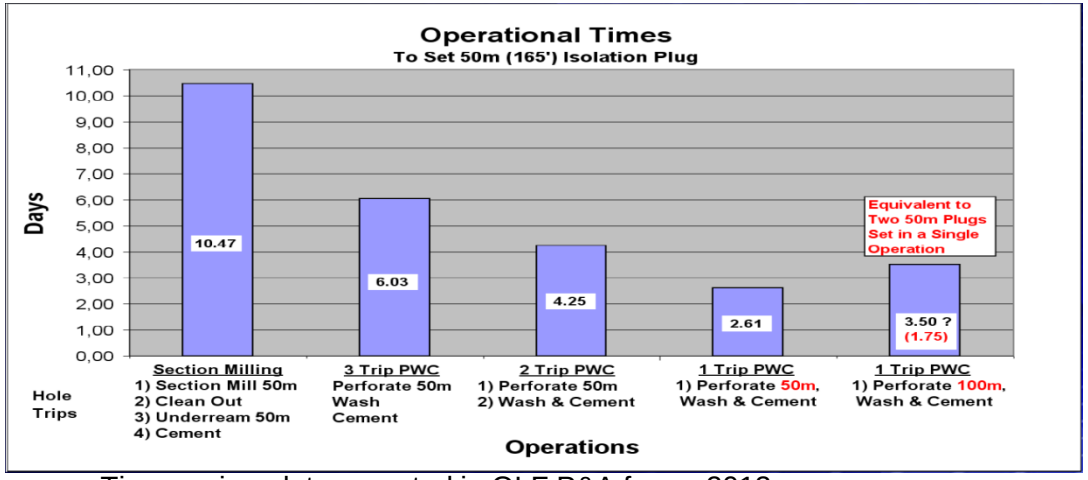

(fig 3)
Wash behind casing before pumping cement


(fig 4)
Release between upper and lower cups


(fig 5)
Pump cement P&A plug

NEW P&A TECHNOLOGIES
EXAMPLE: PERF, WASH & CEMENT - TECHNOLOGY STATUS

- Perf, Wash and Cement.
  - Qualified according to NORSOK rev 4 for one casing string as long as cement drilled out and logged. Ongoing qualification program to allow setting plugs without drilling out and log. Ptil positive to method. Performed a review of one of the major operator in NSC Q2 2014.
  - Currently working on method to qualify cement as a barrier for setting plugs trough two casing strings.



Time saving plot presented in OLF P&A forum 2013

PLUG AND ABANDONMENT TECHNOLOGIES
SUMMARY

Description of need:
- Close to 6000 wells need P&A over next 40 yrs.
- Traditional P&A require 15 rigs continually for the period.
- Annual total cost of 22 billion NOK.
- P&A will draw resources from other value-creating activities.
- Need for radical new technologies that eliminate or reduce rig time.

Value drivers:
1. Avoid large costs to businesses and society.
2. Free up organizational resources for value adding activities.
3. Free up rigs and services for value adding activities.

Applicability and limitations on the NCS:
- 3000 historic wells need P&A.
- Close to 3000 new wells over next 40 years need P&A.

SECTION 5

1. Executive summary
2. Study task, scope and boundaries
3. NCS cost picture and main cost drivers
4. Technology related measures with large cost saving potential
5. Other measures with cost saving potential
6. Recommendations

OTHER MEASURES WITH LARGE COST SAVING POTENTIAL

Other measures have a cost saving potential possibly of the same magnitude as for new technologies.

Measures related to the following topic areas are disussed over the next pages:

- Contracts and incentives
- Culture
- Organization, competence
- Regulations and Standards
- Specialized rigs («fit for purpose» rigs)

CONTRACTS AND INCENTIVES

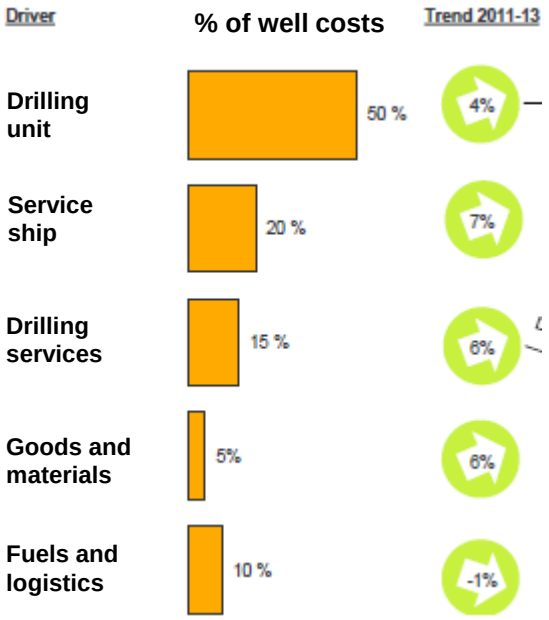
For an average drilling campaign on the NCS, rigs, service ships and oil services contribute to approximately 85% of the total costs. Common for these services is that the compensation is based on time use.

Contract structure and content are outside of the main scope of this study, but during the interviews with industry experts, it became apparent that contracts generally lack incentives to reduce time use.

If better incentives could reduce the time use with 10%, the annual cost savings on the NCS would be in the range 5-10 billion NOK.

Suppliers are rewarded (or not penalized) for not having equipment failures. Introduction of new and potentially more time efficient technologies introduces down-time risks that might not be sufficiently balanced by success rewards.

Cost drivers MODUs



Source: Rystad Energy

Industry expert, oil service company:

"Contracts do not provide incentives for taking on risks. We make our money from the bonuses, and would not do anything that threaten those."

Industry expert, rig management company:

"With time based contracts, only the operator benefits from time efficient operations."

CULTURE

Data from Petoro (page 17) as well as information obtained during the interviews, suggest that comparable drilling operations take longer today than 20 years ago.

Industry experts interviewed attribute part of the efficiency decline to a change in culture that has led to less focus on efficient time use during planning and work execution.

Some illustrating examples from the interviews are: circulating bottom-up several times when once should be sufficient with modern equipment, and going off bottom repeatedly when drilling a section, which also should be unnecessary with modern technology such as steerable systems.

The culture that allows less efficient time use might have evolved from HSE concerns. The working group questions that there is a strong correlation between being more time efficient and increased safety risk. Efficient and safe operations are characterized by being well planned and well executed by highly competent people.

Anecdotes also suggest a culture change in procurement departments that might lead to a loss of time efficiency. According to some of the interviewees, operators on the NCS used to be early adopters of new technologies, whereas today's operators tend to favor traditional, well-proven technologies.

Industry expert, oil service company:

"Drilling ROP in Brazil is a lot higher than in Norway for similar sections. We don't generate more cuttings in Norway with the same ROP"".

Industry expert, oil service company:

"The environment for testing out new equipment was a lot better in the 90-ies. One example is steerable systems, which improved their operational life from 5 hours to 500 hours over a few years time. They would have been rejected if the decision for further development had been taken too early".

WORK PROCESSES AND ORGANIZATION

The interviews revealed time and cost efficiency potential in how work is being organized.

Rig consortiums offer smaller oil companies bargaining power and rig companies longer contract horizons, which they need to justify the investments for upgrading rigs to comply with Norwegian regulations. In addition, rig consortiums provide opportunities for optimizing repair and maintenance processes that over time will lead to better efficiency, e.g. a longer contract horizon gives incentives for repair solutions that last, rather than quick fixes.

The many participants in drilling operations (rig, drilling contractor, service contractors and oil company), cause a complicated interaction pattern, and good planning and cooperation is important for efficient utilization of rigs and equipment. Interviewees pointed to a potential for better tools to facilitate the planning and interaction between the players. Standardization of equipment, and also work processes, would also make cooperation easier. A “best practice” guideline could make planning and operations more efficient.

A need for better planning of maintenance is a recurring theme among the interviewees. Some claim that contracts allow too little time for maintenance, others point to a need for maintenance and repair strategies that would avoid lengthy repair periods when rigs are being re-classed.

Industry expert, oil service company:

“It is a paradox that equipment such as drill bits and MWD tools which should be more robust today than earlier days, fail at the same or higher frequency – this is certainly maintenance related.”

REGULATIONS AND STANDARDS (1/2)
NORWAY SPECIFIC REQUIREMENTS DRIVE COSTS

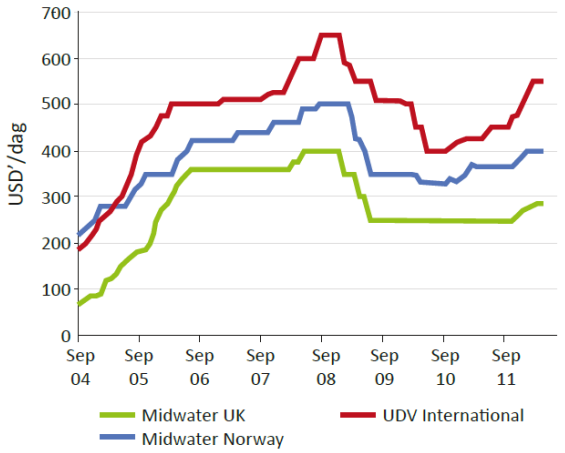
Cost implications of Norwegian rules and regulations for drilling rigs, are discussed in the 2012 report by the MPE appointed «Rig-committee» led by Eivind Reiten. The committee compared rules and regulations in the various North Sea countries. Its main conclusions were:

- Similar intentions behind HSE-requirements in the countries.
- Specific references in NPD-regulations to standards like Norsok and DNV standards, introduce Norway specific requirements.
- Cost implications of Norway specific requirements are limited for new rigs, given a thorough understanding of the Norwegian rules and regulations.
- Intake of rigs that have operated abroad may require substantial and costly upgrades to comply with Norwegian rules and regulations.

In addition to costly upgrades, Norway specific rules and regulations also drive costs by limiting the supply of rigs in the market. The Rig Committee reports a difference of 20% for midwater rigs, which partly is caused by less labor costs in the UK and partly by a segmentation of the Norway rig market.

A segmented market for Norway may generally cause tight supply, but it also put limits on the availability of rigs best suited for particular well operations and as such may lead to too sophisticated rigs being used for simple or standard well operations.

Day rate development Norway vs. GB



Source: Rig Committee Report

Industry expert, rig management company:

"It's important to use the right type of rig. Simple, straight-forward wells don't require heavy rigs constructed for deep water".

REGULATIONS AND STANDARDS (2/2)
RIG COMMITTEE'S RECOMMENDATIONS STILL APPLY

The «Rig committee» report lists the following as examples of areas with Norway-specific requirements:

- Automatic mud mixture – Norsok and DNV requirements.
- BOP control systems - Norsok and DNV requirements more stringent than international standards.
- Electrical systems – NPD refers to IEC standard, whereas many rigs are built and certified to US UL standards.
- Fire water systems – Norsok and DNV requirements differing from internationally accepted systems.
- Pipe handling – NPD requirements of remote handling, which many rigs operating internationally are not equipped for.
- Noise – Norsok requirements exceeding common practice on older rigs.

Since the release of the Reiten committee report in 2012, the Norsok standard D-010 on well integrity has been revised, introducing additional requirements, e.g. related to P&A barriers.

Industry expert, rig management company:

"PSA regulations refer to Norsok, and Norsok standards are therefore perceived as regulatory requirements. It's too demanding to prove that other standards are equally good or better".

SPECIALIZED, «FIT FOR PURPOSE» RIGS

Several of the interviewees point to «fit for purpose» rigs as well as repetitive operations as measures with large cost saving potential.

The Rig Committee report (2012) covers these topics into detail, and the study group supports the observations and recommendations made in the report.

The Rig Committee concludes that use of «fit for purpose» tools specialized for certain parts of, or types of drilling operations, may result in large efficiency gains and corresponding cost savings.

The Rig Committee at the same time warns against a potential loss of flexibility in a small market which may reduce the utilization rate for floaters. This risk needs to be managed by the industry through longer planning horizon for well operations, increased cooperation between licenses, and an increased willingness to utilize new technologies.

Industry expert, rig management company:

«Traditional rig strategy has been to spec rigs to the highest standard, resulting in sledge hammers being used where a hammer would suffice. Statoil's rig strategy is breaking this tradition by introducing different rig categories.»

Industry expert, rig management company:

"It's important to use the right type of rig. Simple, straight-forward wells don't require heavy rigs constructed for deep water".

Industry expert, rig management company:

""Efficiency gains are possible by repeating simple operations, for instance by drilling several top holes at one go without BOP and riser".

SECTION 6

1. Executive summary
2. Study task, scope and boundaries
3. NCS cost picture and main cost drivers
4. Technology related measures with large cost saving potential
5. Other measures with cost saving potential
6. Recommendations

RECOMMENDATIONS

What the industry should do:

- Technologies identified in the report improve value creation as well as safety and predictability of drilling operations. Parties involved in drilling operations should come together and discuss barriers to implementation and measures to reduce such.
- Oil companies should use information in the report to develop business and technology strategies.
- Oil companies should influence rig owners and service companies to consider how the report's information could be used to increase competetiveness.
- Rig owners should consider how their fleet could accommodate the use of promising technologies described in the report.
- Oil companies should take the lead to evaluate how drilling contracts could better share risks and rewards, such that incentives are provided for implementation of promising efficiency improving technologies.
- Oil companies should evaluate how drilling operations could be made more efficient through better coordination between the parties involved.
- Parties involved in drilling operations must ensure that competence is developed to harvest the full potential of new technologies and combination of technologies.
- Time efficiency and performance culture should receive increased attention at all organizational levels.

What the authorities should do:

- The authorities should continue the support of new technology development, and identify ways to better stimulate piloting and first use of new technologies.
- Authorities and industry should stimulate and fund development and testing of new, innovative methods and technologies for safe and cost-efficient P&A (including slot recovery).
- Authorities and industry should continue efforts to create a well-functioning, open rig market, by harmonizing requirements across borders.
- Authorities should ensure that regulations are kept fit for purpose, continue the practice of having functional rather than specific requirements, and be wary of promoting specific technical solutions through references in regulations and guidelines.

What OG21 should do:

- Communicate observations and recommendations from the report to authorities and the industry.
- Facilitate a workshop where technology providers, rig companies and oil companies discuss cost saving technologies, barriers to implementation and actions.
- Work with the major oil companies on the NCS to identify and promote potential field candidates to test out new technologies.

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