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Real Time Data Monitoring Experience Results in Enhanced Safety and Efficiency

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Abstract

This paper is about BP's experience with Collaborative Real-time Environments (CoRE) including the Houston Monitoring Center (HMC), which has resulted in enhanced safety, rig site monitoring and its associated planning, and improved operational efficiencies. Real Time Monitoring Centers have been utilized by industry for some years to improve operational efficiency in drilling processes. BP (operator) has explored extending the effectiveness of such centers by embedding them in a CoRE. In its Gulf of Mexico operations area, this operator has been rigorously applying real-time data monitoring technologies on critical operations with the intent to enhance both safety and operational efficiency through more informed operational decision making. The results of this focused operation will be described in this paper.

The term CoRE is used to describe the physical atmosphere and office arrangement of integrated teams, both operations and subsurface, sophisticated data monitoring applications and communications tools from the office to the rig site. Remotely monitoring key rig site data using highly trained and skilled personnel in a newly designed environment called a CoRE, has resulted in improvements in procedural discipline, efficacy in human factors as they relate to drilling and completion operations, and significantly improved operational decision making. These processes are underpinned by highly resilient systems and meticulous planning, delivering an uptime greater than 99.5%. To improve resilience of the system, the ability to transfer monitoring operations to an alternative location within a short time has been demonstrated repeatedly. This paper will describe the principles and demonstrated results from the CoRE philosophy.

An additional benefit of having key data streaming onshore is regulatory compliance verification by the operations team, which also would allow external review by a regulator. This enhances the compliance verification significantly and allows additional items to be verified or inspected in less time and with less impact on the field operations. The potential benefits to both internal and external stakeholders including regulatory personnel are also described in this paper.

The paper will detail the operator's journey on real time data monitoring of drilling operations which has been utilized by the company for several years. Included is a description of the numerous benefits resulting from applying advanced technologies in real-time monitoring (RTM) to the area of operational decision making including being aligned to potential future industry guidelines or standards. This paper describes the management practices which can be used to foster confidence between geographically separated team members because acceptance by field operations personnel is key to the success of any remote monitoring activity. Finally, the overarching management approach which has contributed to the success of this integrated effort is described by this paper.

Introduction

The operator has achieved significant experience in offshore drilling operations using a concept called the Collaborative Real Time Environment (CoRE). This concept has broken through stovepipes of different disciplines and organizations to provide a streamlined process to plan, supervise, and execute the drilling of offshore wells. Additionally, in the Gulf of Mexico region, operator has instituted a new type of monitoring center, the Houston Monitoring Center (HMC) which is focused on safety in the area of well control monitoring rather than on drilling efficiencies or after action data gathering as has been the norm for the past several decades of monitoring centers. The addition of the HMC not only enhanced safety as it was intended, but also improved efficiency. Real Time Monitoring Centers have been utilized by industry for some years to improve operational efficiency in drilling processes. The operator has extended the effectiveness of such centers by embedding them in a CoRE. In its Gulf of Mexico operations area, the use of the center has resulted in enhanced safety, rig site monitoring and its associated planning, and improved operational efficiencies.

The term CoRE describes the physical atmosphere and office arrangement of integrated teams, both operations and subsurface, sophisticated data monitoring applications and communications tools from the office to the rig site. Remotely monitoring key rig site data using highly trained and skilled personnel in this newly designed environment. Such an organization is successful only if underpinned by highly resilient systems and careful planning, delivering in this case, uptime greater than 99.5%.

As the principles of a High Reliability Organization are being used by other high hazard industries (Weick and Sutcliffe, 2001), the operator is reviewing those priciples and has enhanced learning across the board including the establishment of best practices. CoRE has also provided observable results including improvements in procedural discipline, efficacy in human factors as they relate to drilling and completion operations, and significantly improved operational decision making.

Learnings from Others

The concept of remote monitoring grew in the early part of the 20th century as instrumentation and the technical means to transmit data to a ‘distant’ location grew. Just as a ship’s bridge has evolved to include more and more information from the engine room or other remote parts of the vessel, so too has the ability to monitor complex vehicles from a distance. The aeronautics and space industries provided much of the early evolution of control centers, **Fig. 1**, (Hallion, 1988).

Launching rockets was inherently hazardous so operations had to be conducted from a significant distance. This led to remote monitoring and control on a primitive level. Rules about safety, protocols for operational success, and the type of instruments to monitor and control grew over time. With the evolution of radio telemetry systems in the 1940s, advanced aircraft testing took on an entirely new aspect. It was possible for the pilot to simply maneuver the aircraft into the required environments and flight conditions. Aeronautical engineers on the ground could monitor subsystem performance, flight stability, etc., and direct the pilot to increasingly difficult and extreme conditions.

Fig. 1 Robert Goddard monitoring a rocket launch circa 1930, photo courtesy NASA, NASA-HQ-GRIN

X-plane aircraft testing in the 1950s became a direct primogeniture of human spacecraft control in the 1960s. At first, the monitoring and control was extremely limited due to the limitations on the amount of information that could be transmitted from a spacecraft to the ground. But by the time of the Apollo lunar missions, NASA had overcome many of these technical limitations and the ability to supplement the onboard crew for both subsystem monitoring and planning and control functions had evolved to a high level, **Fig. 2**, (Dethloff, 1993 and Kraft, 2001).

Fig. 2 NASA Mercury Control 1962, Photo courtesy NASA NIX-S62-05139

Perhaps the most significant lesson from the NASA experience is that purely technical monitoring is not sufficient. The lessons of planning, maintaining a strong chain of command, developing configuration controlled procedures, and a series of pre-defined decisions called “flight rules” made mission control an effective function. It goes without saying that highly trained personnel were mandatory in that environment. And a final lesson about the importance of maintaining good working relationships between the ground controllers and the flight crew is definitely applicable to the usefulness of remote drilling monitoring centers in the energy sector, (Kranz, 2000).

During the same period, the US Federal Aviation Administration evolved a complex system of air traffic control centers to ensure the safety of commercial air travel. While these control centers were primarily concerned with physical separation rules and planning for orderly arrivals and departures, the events of September 11, 2001 have lead to the requirement to monitor certain aspects of aircraft flight control systems so that action can be taken if suspicious indications are received from the aircraft.

Large industrial complexes, such as power plants, assembly line processes, and chemical/refinery facilities benefit from control rooms which are remote in a less significant geographical way but which are remote in the sense that the operators are not physically connected with the hardware involved. Practices from these industries are also crucial in development of similar protocols for offshore drilling.

Real Time Monitoring History in the Drilling Industry

Collaboration and decision making are essentially human activities, influenced by attitudes, behaviours and information as well as numerous other physical factors. These two activities are fundamental to the safe, efficient and effective planning and delivery of wells.

The global drilling and completions community recognised the benefits of providing ready access to data and expertise in the 1980s and various Onshore Operations Centres emerged. These early attempts faced technical difficulties as well as acceptability problems, including sabotage and some eventually had to be abandoned. Since then, technical capabilities and understanding has grown and the concept of remote operations is now accepted and widespread. Over time there has been a gradual shift in emphasis from technology, activity and discipline to collaboration, recognising the importance of human factors in their use. Within the last decade, the industry has made much progress in enhancing and formalising its collaboration and decision making capabilities. The word "workflows" figures prominently in both day-to-day dialogue and in the literature and various models have been put forward to describe the collaborative activities.

The operator's interest in collaborative environments started in 1997 with the Norway based Team 2000 project to use information communications technology to relocate people from offshore to onshore (Wahlen et. al., 2002). The knowledge and experience gained in this project was transferred and used successfully in 2005 to create an onshore operations centre (OOC) to support the drilling of side-tracked wells for the UK Andrew Low Cost Drilling project (Sawaryn et. al., 2006). Interest in the approach grew as word of both internal and external successes spread, and by early 2009 collaborative environments had been commissioned in Aberdeen, Baku, Houston, Stavanger and Tangguh and several others were in the planning stage. The business drivers for these centres varied considerably, from managing personnel on board (POB) and sustaining operations through capability and efficiency improvements and supporting technically challenging wells (Booth, 2011).

The operator's approach to collaboration identifies the contributions of people, process, technology, organisation and physical environment and is referred to as the Advanced Collaborative Environment (ACE) 5 petal model. Importantly, the model recognises there is considerable inter-play between these components and that they are not distinct. The ACE concept started as a production operations led initiative in 2003. The concepts of the 5 petal model were adopted by the operator's drilling and completions division soon after, but in the asset based organisation at that time, there were multiple interpretations resulting in different capabilities, identities and names. The early successes were driven locally to meet local needs such as increasing capability and the management of personnel on board (POB) on offshore structures or overcome challenges in remote operations (Pickering et. al., 2008). The concepts embodied in the 5 petal model have endured and still form the basis for today's CoREs.

In the absence of a company-wide approach, the activities were regionally focused and the learning, diversity of purpose, geographical constraints and technical leap-frogging caused the centres to evolve independently. Noticeable differences emerged in the organisation and process elements as well as in the physical environments, (Sawaryn et. al., 2012).

The Collaborative Real Time Environment

The response to this has been the introduction of the Collaborative Real Time Environments (CoREs). More recently, the close monitoring of well control parameters has been introduced in the form of the Houston Monitoring Center (HMC) to provide additional assurance of barriers to well control events in the Gulf of Mexico which is one of the highest activity basins in the world.

The CoRE is prinicipally a visionary concept which depends greatly on the training and personnel assigned to it. The facilities in the operator's Houston office play an important factor in allowing the teams to work productively. The goal of the concept is to break down inter-organization barriers to bring together all the expertise required to execute an offshore well construction. The particular details of the facility in this section are not necessarily critical individually, but the overall concept of a complete team working in close collaboration with modern tools is fundamental.

The application of modern technology and the architecture of the facility are fundamental. The facility is made up of rig pods, huddle rooms, conference rooms, the data wall, and the Houston Monitoring Center all intended to facilitate and encourage the multidiscipline support and input needed for operations, **Fig. 3**. Locating the technical specialists close to, or within the CoREs is a powerful means of connecting this sparse resource with the broader engineering community. It clarifies where engineers may go to for help.

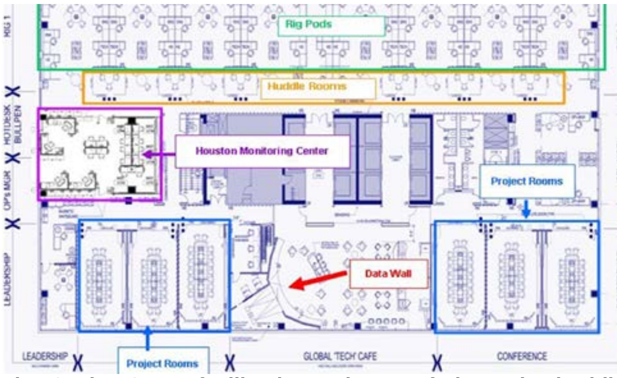

Fig. 3 The CoRE facility is made up of rig pods, huddle rooms, conference rooms, data wall and the Houston Monitoring Center

The rig pods are the critical facility. There are identical rig pods which support each of the GoM (Gulf of Mexico) deep water rig lines. These pods function as the "window" to the rigsites with each one consisting of audio/visual (AV) capability with speaker table, three liquid crystal display (LCD) monitors, 1 quad pack personal computer (PC) and 6 desk work spaces. In these work spaces are located 'rig' aligned leaders, such as the Well Team Leader and HSE (Health/Safety/Environment) Team Leader; and 'well' aligned leaders such as the lead geologist, the cognizant drilling engineer(s). The co-location of these leaders is very important in the efficient transfer of information and in accurate decision making.

Five huddle meeting rooms are located near the Rig Pods to provide small meeting space or private conversations, accommodating four to six people. The room also has a direct connect LCD monitor for display sharing and white board wall space.

Six large bookable conference rooms on the CoRE floor are available for larger meetings. These rooms are equipped with AV capabilities, one large projection screen, four LCD screens, 1 built in PC system, 1 build-in Linux system, and lockable white boards. Typically, the daily morning rig calls occur in these rooms.

The data wall is a highly visible, public display area located adjacent to the common café area, **Fig. 4**. This area functions as a dashboard view of the GoM drilling and completion operations, with twenty-four 46" LCD monitors and a large dynamic projection screen. The Data Wall is driven by 10 rack mounted PCs with four graphical outputs each. The area can also be used for town hall meetings, training, and viewing of critical operations. There is video-conferencing capability for use in town halls, remote broadcasting and training.

Fig. 4 The data wall is a highly visible, public display providing a dashboard view of the GoM drilling and completion operations.

On the CoRE floor, a large PC/server room is equipped to provide up to forty-four different data feeds to the rig pods, huddle rooms, data wall, and conference rooms.

Houston Monitoring Center

The Houston Monitoring Center is also located in the CoRE area. Five well monitoring specialists can monitor up to ten simultaneous drilling operations in this secure, limited access environment. The HMC staff includes wellsite leaders, information technology and services (IT&S) and data transmission support. Technology in the HMC includes 14 wall mounted displays, fifteen quad pack displays, phone communication and digital radios. This facility is fully staffed and active 24/7, unlike the rest of the CoRE that observes regular work hours.

Real Time Monitoring

In the CoRE arena, key data streams from the rig are monitored. The telemetry stream transmitted from the rig includes down hole measurements (Logging While Drilling/Measuring While Drilling or LWD/MWD), pit levels, pump strokes, pressures throughout the drilling systems, hook weight and torque, alarm values such as gas indicators, etc. In all respects, the data collection is not remarkable for a 21st century 5th generation mobile offshore drilling unit (MODU). A key factor is the consolidation of all pertinent data – rig data, 3rd party data from mud logging units and cementing units, and down hole data – all consolidated into one data stream with a common data format that can be accessed by multiple users both offshore and onshore. Data is available in real time but is archived for rapid retrieval so that after action engineering and geophysical evaluation can occur efficiently. Real time data is critical for well control monitoring to prevent escalation of events. The superposition of situational awareness video – such as rig floor and / or remote operating vehicle (ROV) cameras – is important to provide context to remote evaluators. The availability of trained and knowledgeable personnel onshore with the proper software tools to access the data in useful formats has proven to be a critical factor as well. Utilizing seasoned offshore workers in the onshore monitoring center has resulted in rapid recognition of issues. Even more importantly, a close camaraderie and mutual respect has developed between the offshore and onshore workers which are vital to the success of this team effort.

Operational Decision Making

Decision making in critical operations is enhanced by the CoRE by virtue of having all the disciplines represented and engaged as plans are prepared and documented. The potential operational consequences or inherent issues that might arise can be fully explored with robust off ramps built into plans at key points. Most importantly, having all the relevant organizations represented prevents overlooking critical but obscure facts. The efficiency of having a good, well thought through, integrated plan which has been documented clearly cannot be overstated. The CoRE brings together the rig operations personnel with the well specific knowledge, plus the organizational representatives who are knowledgeable about safety, regulatory processes, and logistics. The plans formulated include the rationale for decision making at critical points and the outline of alternative strategies which may need to be employed if circumstances require.

Then, during the execution of the plan, the CoRE team all have access to the real time data both in the work place and via secure internet connections at their residence or travel locations. This allows the team to observe trends and recognize anomalies before they can grow.

Clearly defined “hold points” within the procedures require that data is captured, analyzed and reviewed by both offshore and onshore personnel before operations can proceed. Finally, the HMC adds a layer of additional monitoring for the critical well control functions. Small deviations in gains and losses and other well control related parameters can be quickly addressed if recognized early. All of these factors lead to less time lost troubleshooting and repairing operational errors. Proper planning can also avoid false alarms by providing the diagnostic tools to differentiate between hazardous situations and non-critical anomalies.

Building a monitoring plan for the HMC requires careful definition of which parameters must be monitored and what are the operational limits before corrective action must be taken. Having the plan, tools, and trained personnel available maximize productivity in drilling operations.

The HMC is staffed by a two shift rotation of specialists providing 24/7 coverage. The CoRE normally operates only during working hours, but the facility is available at all hours and during critical operations in the off hours. CoRE personnel can either be physically present in the facility, or participate virtually via teleconference and internet.

Essential Elements

In creating this visionary concept, meticulous attention has been given to the various essential elements; data, monitoring applications, communications, tools, onshore and offshore teams, training, skills and overall resilience.

Data

For accurate decision making, all the historical experience shows that time synchronous, accurate data must be provided. Without data, a remote monitoring or control center cannot serve its purpose. Location of sensors or instruments must be carefully chosen so that critical processes are properly monitored. Calibration of instruments to a necessary degree of accuracy is also important. It is possible in some situations to use a person on the scene to provide information (e.g., gauge a tank level with a measure stick), but in many applications there is no alternative to a measurement device in a place where human beings cannot safely go. An early rule found to be valuable in control centers was to make no decision based solely on one instrumentation point. It can be very easy, even at this stage of technological development, for a single sensor to fall out of calibration, or fail in some other way. Critical decisions must be made with confirming cues. Predefined limits on instrumentation readings must be established for safe operations. Alarm values which indicate a parameter is outside the acceptable range is important, but smarter applications that can detect untoward trends before exceeding safe operating values are more worthwhile.

Having data in a common digital format that can be decommutated into accurate readings for humans to review is vital. Having reliable data streams (radio, satellite, optical fiber, etc.) is critical and having redundant transmission paths has also proven to be vital. Data latency, which is defined as the length of time for data to be received by the end user, must be minimized. With modern systems, data delays of less than three seconds are considered to be minimally acceptable. Finally, having data presented in a time homogeneous manner is critical when determining the interaction of events. Data provided by different servers – potentially from different third party organizations – must be time tagged in a way that the integrated data stream reflects the order of events in the real world.

Data smoothing (periodic sampling) has proven to sometimes lead to incorrect interpretation of the data and is not recommended.

Context or situational awareness provides a way for remote operators to evaluate conditions properly. Not everything can be provided in a data stream. Visual information such as remote video of the rig floor or subsea views from an ROV can be very critical to providing the context for data readings. On scene reports from the human operators at the location can provide additional, vital information that is lacking in the data stream. This data is provided by the internet messaging (chat via Lync) between the Well Monitoring Specialists and the mud loggers, and by telephone conversations from the HMC Wellsite Leader to the rig Wellsite Leader. And of course, it is essential to know what step in an operations sequence is being executed. Without these contextual cues, proper interpretation of the data set will be much more difficult and could potentially lead to operational errors. Fortunately, in today's environment, a multi-pathed set of primary data and contextual data, voice, text ("chat"), and video is easily available even in remote environments.

Resilience

When it was initially planned, the CoRE was planned to use office automation networks, equipment, and software. This turned out to be a real challenge for a system that is required to have up time greater than 99.5% for 24/7/365 availability. Most office systems have regularly scheduled maintenance periods – usually on weekends or at night – to replace hardware or to upload new software. Sometimes these maintenance periods can result in the system being off line for multiple hours. For systems utilized by office workers on the day shift, this is not a significant problem. However, it is unacceptable for a monitoring system which is dedicated toward real time operations which can occur around the clock. The first shockwave to the IT (Information Technology) systems was a requirement to separate out the critical data and communications delivery systems in such a way that the system is never entirely down for maintenance work. This requirement drove a partitioning of equipment and resources and a new way to schedule maintenance in an incremental manner.

Close attention was paid to the individual components in the full data stream from the rig to the CoRE. It became obvious that certain elements – servers, power supplies, antenna, etc. - were potential single point failures which could take down some or all of the CoRE capabilities. The operator made significant investments in providing redundancy, spares, and alternate routing to mitigate the loss of any single element in the data transmission network, **Fig. 5**. At its inception several years ago, the CoRE/HMC recorded up-time of as little as 92%. With improvements in the system as described earlier, uptime is now consistently 99.5% or greater.

A critical factor in minimizing down time is the presence of IT personnel assigned to the HMC 24/7 dedicated to keeping the communications systems active. The importance of having dedicated personnel in the facility cannot be overstated.

Satellite communications issues have become the leading cause of data outages for the CoRE/HMC. The satellite-to-ground links are typically K band frequencies which are susceptible to high rainfall rate attenuation of the signal. The receiving station on the south side of Houston is intermittently subject to intense rainfall leading to signal outages. Proposals have been made to add an additional receiving station which would be geographically separated from the exiting site and thus

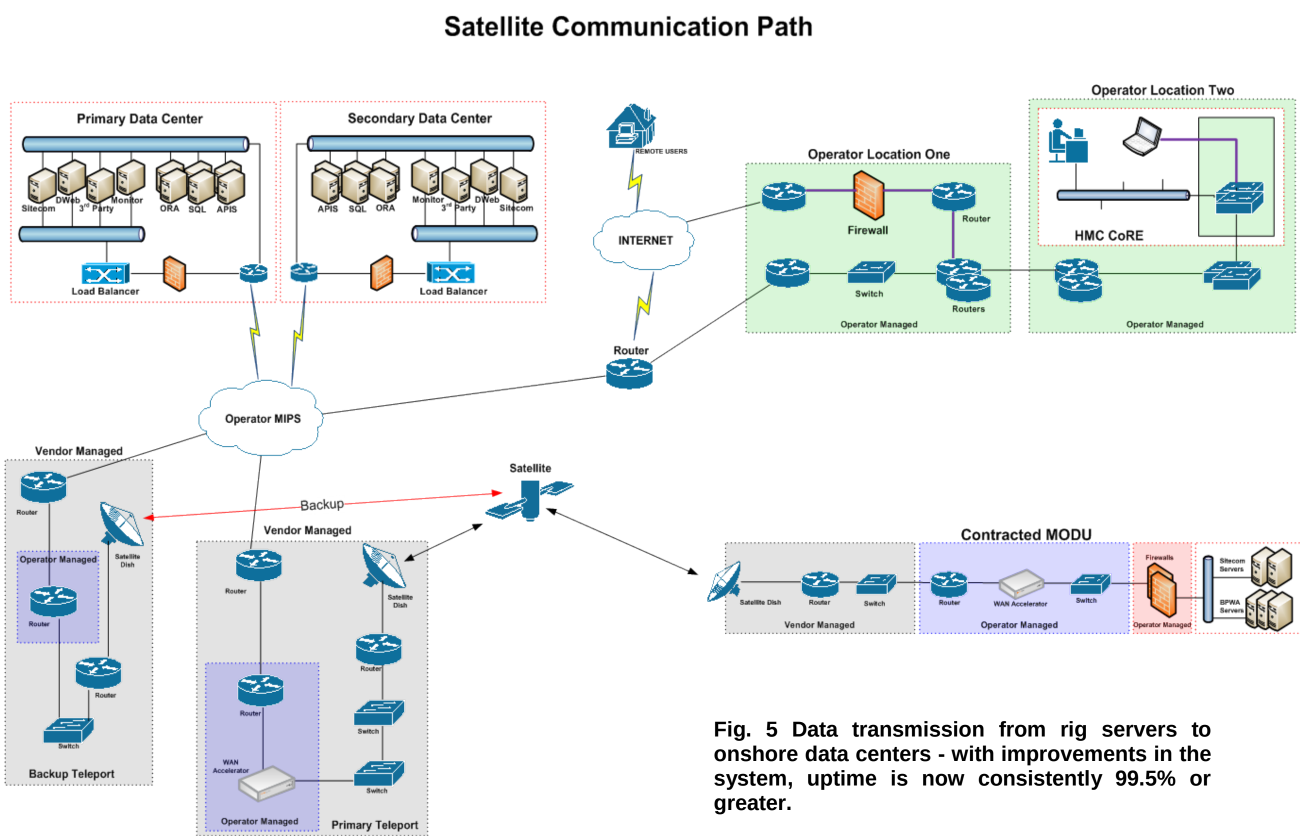

Fig. 5 Data transmission from rig servers to onshore data centers - with improvements in the system, uptime is now consistently 99.5% or greater.

not subject to the same weather patters, or to add a satellite link in a different frequency band which is not attenuated by rainfall. At the current time, the outage rate and duration of events have not justified taking either of these potential improvements, but new technology and providers are continuing to be investigated.

Finally, the drilling units on fixed production platforms in the Gulf of Mexico are attached to fiber optic undersea cables which are far more reliable for data transmission.

Sophisticated Data Monitoring Applications

The operator's WellAdvisor project is driving excellence in engineering and is developing workflow based tools. In doing so the project has recognised the value of a more formal approach and has introduced additional decision making elements.

The WellAdvisor technology flagship project integrates real-time data with predictive tools, processes and expertise with the objective of enabling better-informed operational decisions during all phases of well construction. The flagship has two technology themes:

- Analysis addresses the processing of large volumes of data into information that can be used during well operations to provide early warning indicators of potential issues, - instead of limiting analysis to a post-job review
- Integration combines processes, data, analysis and expertise through advisory 'consoles', and standardised practices, providing a platform for new ways of working

Analyses of non-productive time and well impairments caused during well construction indicate that a proportion of events might have been prevented or operational decisions been influenced if already-available drilling and completions data had been appropriately analysed and presented. That is, early warning indicators were often present, but remained unidentified in the large amount of real-time data.

The synchronized view of information presented by WellAdvisor between the wellsite, office locations, and specialist centres provides a shared situational awareness enabling better informed and more collaborative decisions. Implementation of the system focuses on delivering to staff the ability to interpret the system; and on embedding its use as a part of the day to day operations.

Each WellAdvisor console (console is the term used for Well Advisor application software package including display) presents information and analysis of a particular well construction activity. The first console, designed to support Casing Running was developed and successfully field trialled in the Azerbaijan region in 2011/12, (Mason et. al., 2013). The console is now deployed on 26 offshore rigs and has been used to monitor >250 tubular runs which accounts for a total of 600km of tubulars installed with the console in use, **Fig. 6**. Since implementation there have been no preventable stuck casing incidents where the console has been in use; including the Azerbaijan and Trinidad regions where stuck casing had been an issue and had previously led to significant non-productive time and sidetracks. The success of the WellAdvisor casing running console illustrates the significant gains that can be achieved by using only a few input data streams with robust process, support and expertise, (Israel et. al., 2015).

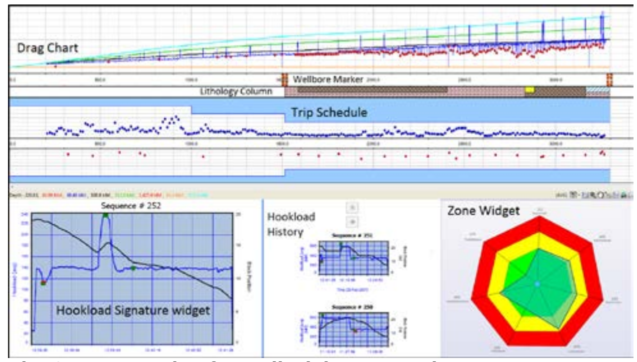

Fig. 6 An example of a WellAdvisor console.

Further development of Consoles is ongoing. BOP Health Monitoring, Remote BOP Pressure Testing, Cement Placement Monitoring, No Drilling Surprises (subsurface risk and uncertainty) and Rigsite Fluid Monitoring (fluid gain/loss) are all in various stages of piloting or deployment. ROP Optimisation, Drilling Operations (hole cleaning and wellbore stability), and Tripping Consoles are also under development.

Data Challenges

The construction of the WellAdvisor is highlighting data challenges in terms of both quality and quantity. Based on only three inputs, some 59 indicators have been identified for the casing running console alone. Some composite consoles require more than 80 inputs and based on these proportions, the resulting complexities are evident. The consoles need to be configured and initialised between activities. These largely IT related tasks can take place at any time during a 24 hour period. The current focus is to maintain the efficiency and effectiveness of this model as the number of consoles grows. A further challenge is the monitoring and interpretation of the console conditions and managing the resulting alerts and alarms.

Teams - Subsurface and Operations

Having multidisciplinary teams and their members highly connected is a significant advantage of the CoRE. There are organizational dynamics which may interfere with the relationship between the subsurface team and the operations team, both on the rig and in the office. In practice, this can lead to misunderstandings, poor communications, and potentially to less effective decision making. One of the pillars of the CoRE is to bring together the subsurface team who is oriented toward a specific well and the operations team which is oriented toward a specific drilling unit. Successful, safe, and efficient well construction requires close interaction between these two teams. CoRE causes the interaction to occur naturally by co-locating elements from both teams, improving both formal and informal communications, and building mutual respect between diverse elements. Full participation by the multidisciplinary team members in scheduled and adhoc video conference calls with the offshore team allow the "One Team" mindset to be utilized more effectively impacting both safety and operational efficiency.

Communications Tools

Uninterrupted communications are vital to keep all the team members working together in geographically distributed areas. The primary means of communication is by telephone and email which work relatively seamlessly between all parties. However, it was recognized early on that the interruption of critical activities by telephone calls could be a significant problem. Therefore, the primary communication tool between the monitors in the HMC and the rig personnel in operations areas such as the mud loggers shack is by internet messaging ('chat') typically using the MicroSoft Lync software. This allows for some time delay to respond if urgent activities are in process onboard. It also keeps an electronic log of the information exchanged for after action review and learning opportunities.

Satellite phone link is also available in case the primary circuits are interrupted. Digital Radios utilizing Internet Protocol (IP) connectivity are also installed on each of the drilling rigs in the GoM fleet and within the CoRE.

Training and Skills Required

Currently, the HMC personnel are trained with a combination of classroom work (Well Control School) and on the job training in the HMC. As part of the onboarding process, an experienced HMC Well Monitoring Specialist acts as a mentor and trains the new hire with regard to HMC Operating Procedures, communications protocols, and software usage. Prior to the new hire actively monitoring operations, they have to illustrate competence to their mentor and HMC management through shadowing exercises. Tabletop training has also been utilized, and the future goal is to participate in simulator based training as part of in-house advanced well control training course currently established in one of the operator's training centers.

Typically HMC hires have been made from the ranks of experienced senior offshore personnel. Coming from this background allows HMC well monitoring specialists to possess significant understanding and experience with offshore operations including culture, limitations, and capabilities. Direct working experience with offshore personnel enhances communication with the offshore teams.

Procedural Discipline

Procedural discipline is driven through the rigorous definition of roles and responsibilities and the introduction of a combination of operational hold points and escalation procedures. A key principle is that the rig remains the primary source for operational decisions. It is acknowledged that this statement may be challenged in the future by unmanned and autonomous operations.

Roles and Responsibilities

In establishing the HMC, the decision was taken that it would be focused on well control. That is, the data being monitored focused primarily on well control (pits, pumps, pressures) and not with any other areas. At the same time, decision making remains with the previous established teams; the onshore teams plan the operations,

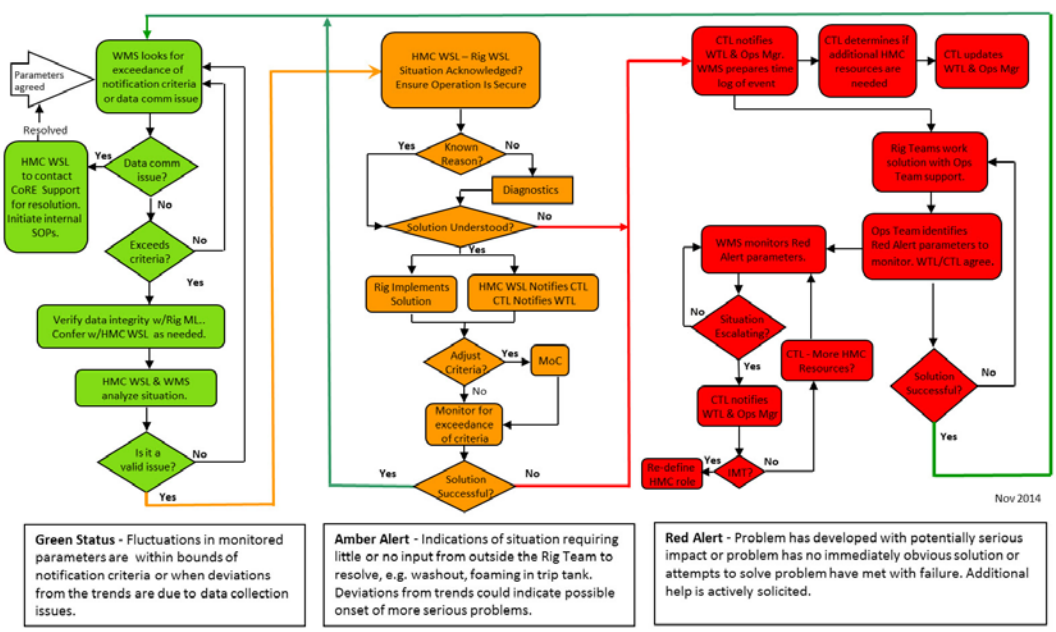

Fig. 7 Houston Monitoring Center Alert Escalation Procedure Flowchart

and the offshore execution is performed by the driller, toolpusher and well site leader as is the standard practice. The HMC provides a third level of monitoring for well control situations. In that regard, the HMC monitors, assesses and alerts the offshore rig team to impending situations and alerts the onshore management team so that they can bring appropriate resources to bear in problem solving. To drive an efficient culture of operations that includes the type of monitoring done by HMC, a single escalation protocol has been developed which is the principle guide for the HMC, **Fig. 7**.

HMC as a Barrier

At the same time, the HMC has focused the team's attention on documented, stable, controlled procedures and alarm values for well control related parameters. At this time, every critical drilling operation has a predefined set of limits for critical parameters to be monitored which is communicated to both offshore and onshore operations. The HMC represents another barrier with regard to well integrity, reducing both the occurence and likely severity of undetected alerts, **Fig. 8**.

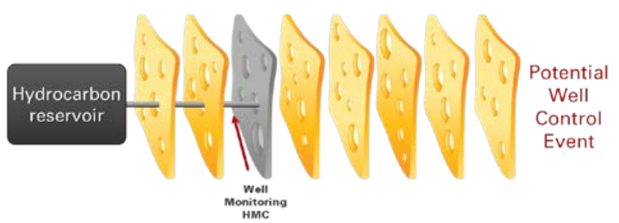

Fig. 8 The HMC represents another barrier with regard to well integrity

Enhanced Safety and Compliance

There are two indicators that show that the CoRE and HMC have enhanced safety of critical drilling operations. These indicators include the responses to low severity alerts and the decreasing number of alerts. Both indicate that the CoRE is a learning organization which is a critical part of being a High Reliability Organization.

Responses to low severity alerts include providing additional sensors for redundancy or moving a sensor to allow readings to be more consistent as the MODU rocks in metocean conditions. These responses have also informed subsurface teams when formation changes are encountered including by providing rig based tests that distinguish between normal background readings such as on the gas detector and when increased background gas is experienced.

As additional evidence that CoRE is a learning organization (as defined by High Reliability Organization theory), the following figure shows the number of HMC alerts over an operational time period as shown. In this histogram, communications outages have been deleted leaving only the other causes for HMC alerts on key notification parameters such as increased gas counts and tripping displacement variences. An alert is defined as any given reading from a sensor straying outside of written ranges pre-documented in a monitoring plan. Even though the number of active rigs being monitored has increased in the Gulf of Mexico, the total number of alerts decreased over the time period shown, **Fig. 9**. The fluctuated nature of this graph represents periods of more or less actual drilling activity, but the general trend is downward.

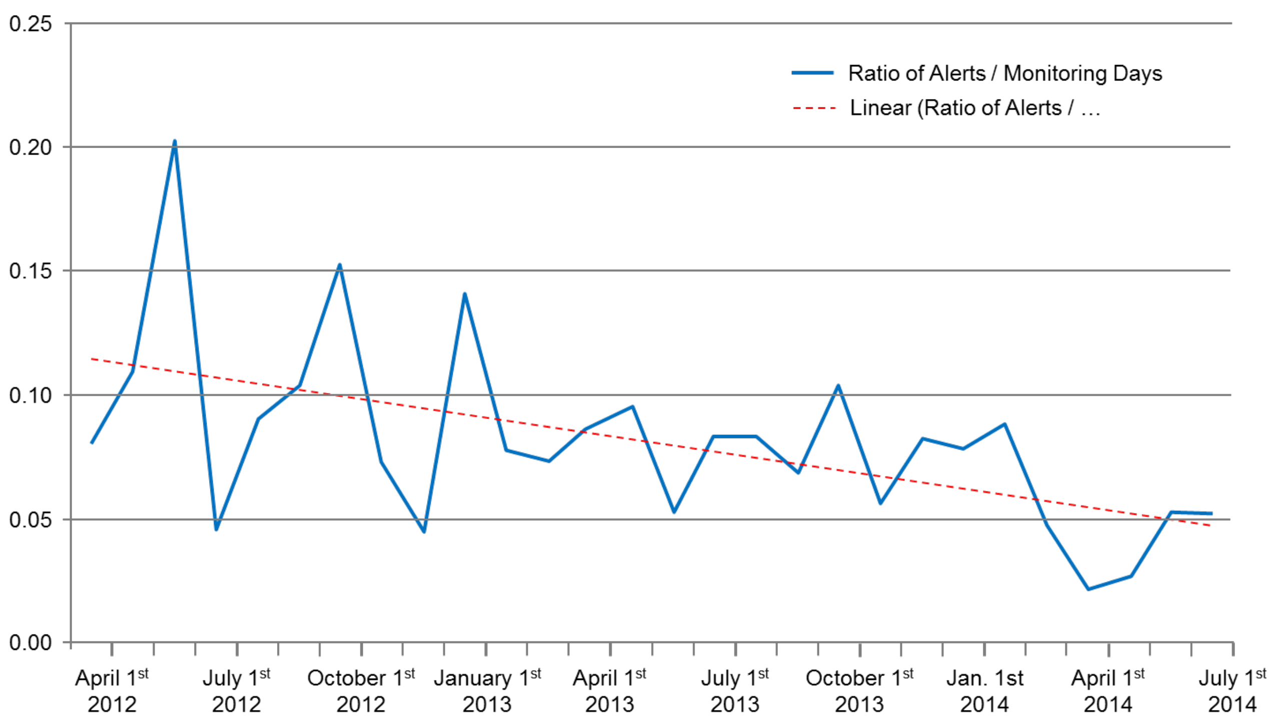

Fig. 9 The ratio of alerts to monitoring days exhibits a steady downward trend since the HMC was introduced

Managing Well Collision Risk

The operator developed a real time process safety workflow to manage well to well collision risk. This workflow, which was enabled by the CoRE processes and structure, involves the streaming of real time survey data to a survey database repository and peforming complex proximity scans to determine the distance and direction to the offset wells from the subject well being drilled. The scan output from these calculations are then plotted on a real time, Traveling Cylinder North Reference Plot and on a Ladder Plot, using a predefined graphical interface (GUI), which is displayed simultaneously in the GoM CoRE and the rig floor, **Fig. 10**. This GUI, is also available to a predefined user group and can be displayed on any smart device (e.g. phone or tablet) to allow for multidisciplinary collaboration.

Depending on the allowable deviation from the plan (ADP) to the minimum allowable separation (MAS) distance or no go barrier line, steering decisions are made based on real time projections. This workflow is in line with American Petroleum Institute Recommended Practice 754 and is considered to be a forward look ahead leading indicator, which shows where the bit is headed instead of a lagging indicator which shows where the wellbore was drilled. The workflow also has a protocol for escalating the probability and severity of a potential barrier breach, up the management chain, based on the ADP calculated, to make real time decision based on an internal risk process.

The workflow is currently deployed in a semi-automated format to allow QA/QC (Quality Assurance/Quality Control) of the data by one of the GoM well placement technical specialists. The workflow is also designed to send real time, text, text to voice and email based on the real time anti-collision protocol to alert users on potential collision risk as drilling progresses. The system used to disseminate the real time messages to the end user is fully auditable and time stamped for traceability, (Goobie, 2015).

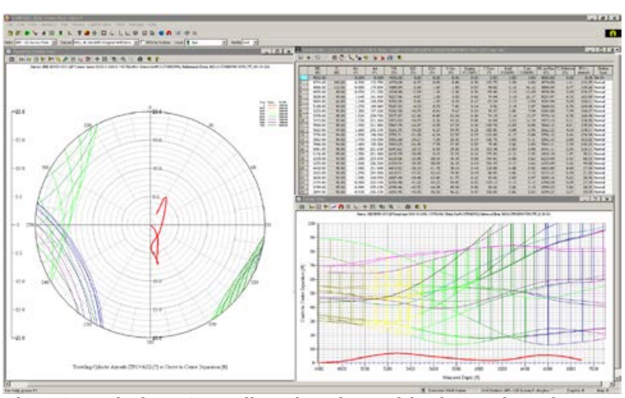

Fig. 10 Real Time GoM directional graphical user interface.

The CoRE's potential in safety management has been realised as usage has matured. Best practices with proven track records for inprovements from other industries have been incorporated. While it is too early to make extravagant extrapolations, it can be stated with surety that the CoRE and HMC have made tremendous contributions to preventing and mitigating incidents.

Regulatory Compliance Verification

Having monitoring centers such as the HMC facilitates regulator access to many operations simultaneously and remotely. This access minimizes the regulator's time spent on helicopters or boats and allows them to focus on specific aspects of regulatory inspection across numerous rig operations. It would also allow the regulator to witness safety critical tests or inspections remotely.

In the future, US based regulators such as the Bureau of Safety and Environmental Enforcement (BSEE) may be able to carry out part of their work at the HMC. For example, certain Blowout Preventer testing could be witnessed by BSEE, the US regulator. With the advent of BOP monitoring (a WellAdvisor console) in the CoRE, it is possible for BSEE to send their regional personnel to the non-hazardous office rather than going to the expense and time required to travel offshore to the drilling platform to monitor this critical safety testing.

Other Benefits

Collaborative environments have been described as "increasing the team IQ", (Wahlen et. al., 2002). Benefits were sought across a wide range of both technical and non-technical activities, but with the CoRE, particular emphasis was placed on those activities in the list and marked with an asterisk. These are still of great importance and interest, but today benefits are being sought from all the other areas too.

- Service level and communication onshore and offshore*
- Team collaboration exhibited*
- Initiative / proactive problem solving*
- Equipment availability and reliability
- Delivery and data quality
- Provision of qualified personnel
- Pre-job planning
- Safety attitude / result
- Improved efficiency

Improved Operational Efficiences

The operator has an internal process that promotes the sharing of expertise and good practice between the operating regions and provides the focus for the documenting, sharing, influencing and engaging of technology between the CoREs, Information Technology & Service (IT&S) and third party technology providers. The CoREs across operating regions have played a significant role in supporting both the development and deployment of the casing running console and the other consoles that are now following.

Fig. 11 Wash-out in an under-reamer, concealed behind the arms

Fig. 12 Wash-out in the pin end of a jar

CoREs help the move from crisis resolution mode to a more predictive mode. In one centre, two washouts were identified by CoRE engineers and brought to the attention of rig personnel. The average non-productive time (NPT) associated with a lost in hole event is of the order of 15 days and together, these two events could have resulted in 720 hrs NPT if no action had been taken. **Figs. 11 and 12**. In both these cases the pressure changes were described as hardly discernable. Technology limitations make it difficult to distiguish a trend from data noise even with the application of physics based models for detecting small deviations and distinguishing these from other background noise, (Cayeaux and Daireaux, 2013).

In smaller hole sizes the low annular clearances makes the equivalent circulating density (ECD) sensitive to the pipe reciprocation rate. After a high density pill was pumped the pipe was reciprocated and on the downward stroke the pipe velocity was 0.87 m/sec. It increased the surge pressure, bringing the ECD closer to the ECD limit and the risk of formation fracture and induced losses. In the same way, pre-well modelling and real time ECD data is used to limit ROP and selectively back-ream sections to optimise hole cleaning and avoid overloading the annulus.

Next Steps

The continued rollout of all the applicable WellAdvisor consoles to the operator's worldwide fleet is next. One of the WellAdvisor consoles, the BOP health monitoring, will allow more efficient troubleshooting of BOP issues to take place. Inclusion of WellAdvisor consoles will make monitoring of activities more efficient both onshore and at the rig site.

As a CoRE exists in many of the operator's regions, the HMC remote monitoring experience is being evaluated for potential expansion beyond just the Gulf of Mexico. Also, according to the most recent US Government Department of Interior budget justifications, the US Federal government agency charged with regulating energy activities in the Gulf of Mexico, the Bureau of Safety and Environmental Enforcement (BSEE) is contemplating how remote monitoring may be used by regulatory agencies to improve and increase regulatory oversight of critical offshore operations and equipment. (US Government, Dept. of Interior, Bureau of Safety and Environmental Enforcement, "Budget Justifications and Performance Indications Fiscal Year 2015", Government Printing Office 2014, reference pages 5-8, 15, & 42).

Conclusions

Continuous improvement in safety and efficiency in drilling, completion, and workovers can be accomplished by the use of collaborative real time environments which break down the organizational barriers allowing for better communication, improved decision making, and enhanced safety in operations. Lessons learned internally and from other industries can enhance the high tech operations of the future for well design and construction in increasingly complex environments. Important structural conditions are:

- Decisions are informed by remote monitoring and assessment
- Remote monitoring processes need operational context or can cause unintended outcomes

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SI Metric Conversion Factors

ft x 3.048*	E-01 = m
in. x 2.54*	E-02 = m

*Conversion factor is exact