Planning and Drilling Wells in the Next Millennium

Computing technology is changing the way engineers and geoscientists work together to plan and drill wells interactively. Project teams can now use specially designed software to capture best practices and integrate all available data. The results are optimized drilling and improvements in cost control, safety and efficiency.

Until recently, exploration and production (E&P) projects that led to drilling a well were viewed as a sequential series of separate tasks rather than as a continuum, or a smooth workflow, and seldom involved drilling engineers. Geologists generated subsurface maps using formation tops picked from well logs. Geophysicists mapped seismic data to confirm, refine or expand the geological interpretation. Once a drilling target was selected by the geologist and geophysicist, the location was provided to the drilling engineer to begin planning and designing the well. In this manner, the project was handed off from one person to the next as tasks were completed without necessarily sharing the relevant data that supported critical interpretations and decisions. In fact, databases were generally discipline-specific, incompatible and unable to share or exchange data readily.

Procedures for interpreting well logs or seismic data, generating maps, performing log and engineering calculations, and planning well construction varied from one professional to the next. The lack of interaction and continuity among project participants often resulted in interpretations and methods that were not challenged or tested, and solutions that sometimes involved estimates and compromises rather than rigorous technical analysis. Industry newcomers faced a steep learning curve until they achieved sufficient training or experience to decide for themselves how to accomplish critical, often interpretive tasks correctly.

In those days, iteration and multiple scenario planning were not performed unless a particularly costly or high-profile project was involved. The lack of routine iteration was in
part a consequence of the difficulty and time necessary to revise and reproduce hand-drafted maps and well plans. Problems may be compounded in the stepwise approach to projects if the objectives of geologists and geophysicists differ from those of drilling engineers. This lack of teamwork ultimately means that reserves may be missed because of poor collective understanding of assets and effective means of exploiting them.

Multidisciplinary asset teams are now working together more effectively to reduce cost, risk and delay in all aspects of the workflow from the beginning of exploration projects to the end of the productive life of a field. This new, optimized process stems from using integrated software and a shared database. This change parallels a trend in the industry toward increased accountability of asset team members to manage and improve asset value.

The increase in teamwork comes at a critical time. Cost is more of an issue than ever before. New discoveries are typically smaller and more subtle. Some of the most promising environments for exploration and production are harsher (deep-water and high-pressure, high-temperature environments, for example). As existing oil fields mature, recovering the remaining reserves is increasingly difficult. Operators must leverage all available intellectual capital and data, whether historical or real-time, to compete with other operators and to compensate for depressed crude oil and natural gas prices.¹

Efficiency, cost control and risk reduction in all phases of the exploration and production workflow, but particularly those that optimize the drilling process, have the potential to temper E&P spending. In this article, we focus on the drilling workflow, that is, the portion of the E&P cycle from identification of a drilling target through well construction. In the drilling workflow, technical integrity, or the use of skills in a core competence that ensures a high level of performance and adherence to technical standards, is achieved with the help of software applications whose algorithms reflect the best industry practices. We begin by examining a traditional drilling workflow and then describe how the process has been improved by using integrated software to achieve consistently sound results.

**Traditional Drilling Workflow**

As the traditional drilling workflow was accomplished through a series of disconnected steps, project participants did not benefit from sharing of data, interpretations and experiences (next page, top). After geologists and geophysicists selected a target, engineers assessed the feasibility of drilling to it. If the target were unacceptable from a drilling viewpoint, time-consuming iterations to settle on a mutually satisfactory target ensued.

Once a satisfactory target had been identified, engineers calculated pore pressures and fracture gradients to design the casing program. These calculations and designs could vary widely depending on the expertise of the engineer and company policies and procedures. Typically, the next step would be for engineers or service companies to design mud and cement programs on the basis of the operating company’s requirements. The input data for these designs would be given by telephone or on paper rather than electronically. Again, depending on the companies and engineers involved, as well as the drilling environment, engineering practices varied considerably. Operations proceeded once permits were obtained and other logistical arrangements were made.

During drilling operations, real-time data might have consisted of a daily drilling report and mud log transmitted by fax or telephone to the operator’s drilling department, data not necessarily disseminated to the project geologist, geophysicist, petrophysicist or reservoir engineer. If unanticipated drilling events occurred, the project participants would share information and work together to resolve problems, but real-time changes involving the entire team were often impractical given the time constraints and communication tools available. More recently, multidisciplinary teamwork and new software tools have demonstrated the benefits of an iterative method, real-time data sharing and consultation among project team members.

**Ideal Drilling Workflow**

An optimized workflow allows team members to collaborate fully without consuming additional time (next page, bottom). The success of integrated geological and geophysical (G&G) software in streamlining exploration has instilled a desire for a complementary suite of integrated applications to improve the drilling workflow. Thus, the ideal process described next assumes the use of such tools and a common, shared database.

Geologists and geophysicists select a drilling target, update their interpretations and visualize the proposed well trajectory with G&G interpretation tools. Engineers select a surface or kickoff location using geological data and employ drilling engineering tools to design the optimal well path to satisfy drilling constraints. Because these processes occur simultaneously and data and interpretations are shared among the team members, iterations between geologists, geophysicists and engineers in selecting target and surface locations are fewer and faster than before.

Once the surface location and trajectory have been decided, the well prognosis for the lithologic column, pore pressure and fracture pressure are determined. This might also require iterations of the surface location and trajectory to avoid drilling hazards such as shallow gas or overpressured zones. Next, the engineer designs the casing program on the basis of geological interpretations and offset well information. Service companies can then assist the engineer with the appropriate drilling mud program, cementing program and other well construction services. At the end of the planning phase, the operator applies for permits and makes logistical arrangements to commence drilling.

It is during drilling operations that an ideal workflow scenario allows the operator to reap the considerable benefits of data sharing and collaboration among the team members. Real-time updates while drilling help optimize operations, avoid hazards and anticipate problems as the entire team works together sharing information. New real-time data are generated and input into the database in the appropriate format to update engineering calculations, so engineers need not reenter data into different applications at the risk of data entry errors. As experience grows and historical data accumulate in the database, the needs and abilities of geologists, geophysicists and drilling engineers will be understood better from the broader perspective of a shared database. Operations can proceed more efficiently and at lower cost and risk.

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Traditional drilling workflow. A linear workflow requires more people and incurs higher cost because of inefficiency in the process. Iteration is time-consuming and costly, particularly at the stage when drilling target selection occurs. The lack of a shared digital database inhibits integration of data and interpretations among team members. Integration, in this situation, depends on human interaction as well as duplication of data entry efforts in incompatible databases.

Ideal drilling workflow. With team members using the same database and model of the earth, the drilling process becomes less linear. At each point in the process, validation occurs earlier, saving time and money. Inferior solutions are weeded out early in the process. The use of real-time data allows optimization of operations during drilling. After completion of drilling operations, results are readily available in the database to improve subsequent operations.
Asset managers need to get more from existing resources. One solution is to provide better software tools that increase the efficiency of each person involved.

Many exploration and production companies have carefully examined their unique drilling workflow to maximize the productivity of each multidisciplinary team and the value of each asset. Schlumberger has worked with a number of operators to identify the process best suited to that company and the changes necessary to achieve it. Several common priorities emerged from these studies:

- The ability to move data and surveys easily between G&G and drilling software to finalize the drilling target early
- Standardized survey, well naming and coordinate systems
- Three-dimensional workspace and multi-user access with conferencing flexibility so that all team members, be they at the wellsite, in the operator’s office or in a service company office, can access data and the latest interpretations
- A link between G&G models and well planning and design systems
- The use of real-time data in application format, so that data entered in one application are automatically available in all other applications
- The ability to move targets and surveys easily from these studies:
- The role of digital data and a database architecture that promotes sharing of data and interpretations for the duration of a project. The amount and variety of data used to plan and drill wells are mind-boggling: seismic data, well logs, mud logs, core samples and their descriptions, drilling fluid reports, directional surveys, drilling histories and production histories are but a few examples.

A clear understanding of both the existing and ideal workflows is essential, requiring a time commitment up front to assess possible scenarios and solutions, such as what software to use, and the roles and responsibilities of each team member. Willingness by team members to adapt and improve can ease the transition from the traditional method to an improved process using new software. Many professionals are reluctant to abandon products with which they are familiar, even in favor of those that are better integrated. This is related to another cultural obstacle, a fear of many professionals—being replaced by computers. The reality is that as reserves become more scarce and difficult to exploit and wells become more complex (multilateral and extended-reach wells, for example), multiple hypotheses or scenarios must be evaluated.

Asset managers need to get more from existing resources. One solution is to provide better software tools that increase the efficiency of each person involved.

Technical Hurdles

Integrated software to streamline the drilling workflow is a key to improving the process. Among the technical hurdles that must be addressed, perhaps most pressing is the need for digital data and a database architecture that promotes sharing of data and interpretations for the duration of a project. The amount and variety of data used to plan and drill wells are mind-boggling: seismic data, well logs, mud logs, core samples and their descriptions, drilling fluid reports, directional surveys, drilling histories and production histories are but a few examples.

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Integrated Drilling Software

All software programs, even those performing common engineering calculations, must be validated: the underlying algorithms must reflect appropriate, correct approaches to a given task. A management system in which the workflow, software and underlying policies and procedures are sound ensures both technical integrity and appropriate management of information used in the system.

Several companies have developed individual software tools to perform specific tasks in the drilling workflow. Schlumberger also developed a number of applications to assist with well planning and design, cementing and other tasks. As integrated project management became a key concern, the need to use all the applications and available data together led GeoQuest to integrate its applications, which are collectively called the Drilling Office system (next page).

More than merely performing specific tasks and integrating them seamlessly, the Drilling Office system had to meet the Schlumberger standard of technical integrity, meaning that it had to meet technical standards of performance, reliability and robustness for a given project: the workflow, the applications used in the workflow, and the underlying methods and calculations reflect appropriate procedures and technology. Each application uses validated algorithms for each task, and within each task a selected process or flow reflects appropriate technical procedures for performing that task.

The Drilling Office suite currently includes:

- The PowerPlan modules for well trajectory planning and design, torque and drag, anticollision analysis, bottomhole assembly (BHA) design and hydraulics analysis; the CemCADE tool for cement design and evaluation; the QLA well log analysis software; the MudTRAK application for drilling fluids management; the SideKick gas kick and underbalanced drilling simulator; the TDAS Tubular Design and Analysis System casing design system; and the WEST Wellbore Simulated Temperatures program. Like all GeoQuest products, the Drilling Office system is Year 2000-ready. Validated by both Schlumberger and the industry, these applications reflect best practices. The commercial software has been used extensively within Schlumberger. For example, Dowell engineers have used the CemCADE program for over ten years to design cement jobs and Anadrl engineers have planned hundreds of directional wells using PowerPlan modules.
New applications in development include the WellTRAK system for well tracking and reporting, a unique drilling data management system. The WellTRAK program is used at the wellsite to capture drilling data and knowledge. In addition, it allows actual drilling activities to be tracked against the original plan so that the project team can readily identify suboptimal conditions and unplanned events and their costs. A link between the WellTRAK program and the Finder corporate database will provide data management tools for well construction data as well as G&G information. Enhancements are under way to allow engineering calculations to be updated and calibrated using operations data while drilling. Reporting features that ensure compliance with quality control procedures are also being developed for the software.

These modules can be used as relatively inexpensive stand-alone applications or as part of a fully integrated system that is designed to allow third-party applications to be linked. The software runs on a personal computer (PC) using Windows NT 4.0 or Windows 98 or 95 (with a minimum of 64 MB of RAM) and a recommended processing speed of 166 MHz or greater.

In any software package, user friendliness is key to acceptance and training. This is particularly true for integrated drilling software because workflow analysis has shown that drilling engineers often use the software intermittently and have little time to learn new packages. Drilling Office applications follow the standard Windows “look and feel” to shorten the learning period and accommodate cross-disciplinary use. End users who have worked with only one module can learn the entire system quickly. The modules will eventually have a more common look and feel, which visually reinforces the movement of data and calculations from one application to another.

The Drilling Office suite is based on the GeoFrame heterogeneous computing environment that uses the Standard Data Model developed by the Petrotechnical Open Software Corporation (POSC). POSC is a nonprofit organization supported by Schlumberger and other industry sponsors. The Standard Data Model was initially designed for G&G data, so Schlumberger had to add the drilling view of data to the model. The applications in the various domains are designed to allow end users to access relevant data without being overwhelmed by data they do not need—drillers do not see most G&G data unless they seek them.

Future database functionality will include improved access privileges, whereby only the owners of a particular interpretation, the project geologists, geophysicists and engineers, can change the interpretation, but the interpretations appear to others as “read only” versions. For example, geophysical interpretations by the project geophysicist or formation tops edited by only the geologist can be viewed by well planners. Versions of interpretations are retained in the database, so if personnel changes occur during a project, the evolution of a particular interpretation can be established and reproduced, which prevents unnecessary, expensive duplication of interpretive effort.
Shared earth model. A central project database houses the numerical representation of the subsurface, the shared earth model, which is developed from geological, geophysical, petrophysical and drilling data. The shared earth model is used in the drilling workflow to improve drilling planning and operations. The database can be expanded, and the model enhanced, by adding real-time drilling data.
Changes in the geological interpretation affect the well design, so a link has been developed in the Drilling Office system between well design steps and the shared earth model. The shared earth model is a concise numerical representation of the subsurface based on geological, geophysical and petrophysical data and models or simulations generated from them (previous page).

Such models, however, are inherently uncertain because of limited subsurface data, measurement errors and, in some cases, incorrect models. Integrated software, the appropriate database and a shared earth model allow real-time flow of data and interpretations to improve decision-making during planning and operations.

The shared earth model affects many areas of well planning, including selection of surface location, trajectory design, pore pressure prediction and wellbore stability, to name a few. The use of shared earth models for well planning has already had a positive impact in a number of field development projects by reducing drilling costs due to wellbore instability and stuck pipe. The pending release of GeoFrame version 3.6 will, for the first time, give drilling professionals using the Drilling Office suite on a PC direct access to the shared earth model developed by geoscientists on UNIX workstations to improve the drilling planning and operations workflow.

Implementing Integrated Drilling Software

As is true of any fundamental change in how something is done, integrated drilling software is not a panacea. This new software consists of a set of tools, but does not automatically dictate a particular workflow. Therefore, to realize the maximum benefit from the Drilling Office system, companies that adopt the system must evaluate their procedures critically and carefully. A given workflow can be modified to suit individual requirements because the software is modular and flexible. In addition, if the entire suite of applications is not needed, a particular module can be used, such as a single application on a stand-alone computer at the wellsite. The software facilitates the iterative nature of teamwork to achieve the best planning and real-time optimization of operations. Iterative and collaborative project planning and execution are enhanced by making individual applications compatible, as the following generic case study illustrates.

At the start of the drilling workflow, geoscientists typically identify drilling targets on the basis of attractive potential pay rather than the feasibility of actually drilling to the target, which is the primary concern of the planning engineer (above left). With properly integrated applications, geological and geophysical data and interpretations in a project database are accessed with software that generates a preliminary well trajectory to select a drillable target. In the past, selecting the optimal drillable target from a number of choices was a time-consuming process. With integrated software and a shared database, iterations between engineers and geoscientists are reduced in number and duration while achieving superior results (above right).

References:


Once a target has been selected, the optimal well design is created. The well design application in the PowerPlan module uses input design constraints to rapidly create both plan view and vertical section plots. The design includes annotations of formation tops, casing seats and other critical points (left). Collision avoidance is achieved through the use of the Close Approach module and survey data from offset wells for anticollision analysis (below left). These applications, along with the ones that follow, are used to create drilling proposals quickly. If the area of the well target can be enlarged without compromising well objectives, further cost savings might ensue.

Information about offset wells is accessible in the database and used to improve drilling performance in successive wells. BHA selection is optimized during initial planning or during drilling by using the BHA Editor and DrillSAFE Drillstring Forces Analysis modules in the PowerPlan application (next page, top). In complex wells, such as extended-reach drilling situations, BHA performance is especially important to the success of the operation. The DrillSAFE module is routinely used for both torque-and-drag analysis and BHA tendency, including computing build and turn rates according to the hardness and other characteristics of formations drilled. Output from the DrillSAFE module is graphical and numerical and capitalizes on both historical and real-time data.

With the PowerPlan Hydraulics application, drilling experience can be used to improve hole cleaning and circulating hydraulics (next page, bottom). Circulating pressure losses and equivalent circulating densities are calculated, which allows bit parameters, motor performance and hole cleaning to be optimized using the module’s validated algorithms (see “Using Downhole Annular Pressure Measurements to Improve Drilling Performance,” page 40).²

³ Chapman, reference 4.

^ Anticollision traveling cylinder plot. A traveling cylinder map generated using the PowerPlan anticollision tool is valuable for both planning and drilling wells in densely drilled areas, such as from an offshore platform. The planned or actual subject survey is always at the center of the plot and the offset wellbores (red lines) show the distance and direction from the subject well. Real-time directional survey measurements while drilling are used to update the map and reduce the risk of collision with existing wells.
Bottomhole assemblies. The BHA Editor can be used for well planning. During drilling operations, real-time data allow drillers to optimize BHA configuration and performance. The up-to-date information and new software capabilities are especially useful in complicated drilling situations, such as extended-reach drilling. In this view of the BHA Editor screen, the driller displays a schematic diagram of the BHA in use (center) and its performance specifications (right). In the left part of the view, the driller navigates to detailed views of the drillstring.

Wellbore hydraulics. The Drilling Office system contains a wellbore hydraulics module that can help improve hydraulics planning and operations. The wellbore hydraulics tool allows calculation of pressure loss (left), equivalent circulating density, and motor performance (right) and hole cleaning analysis.
When well construction begins, real-time data are available to all team members so that operations are optimized and hazards are anticipated and avoided. The well design can be modified if predrill predictions are not correct, such as when a formation top associated with a casing point is higher or lower than predicted.

Planning might involve a spectrum of possibilities, whereas operations occur within a limited range of conditions. Individual modules of integrated drilling software make use of different algorithms depending on the operational ranges or assumptions. Real-time changes during operations are incorporated readily into plans to improve predictions and anticipate potential problems. For example, as a mud system changes while drilling, hydraulics calculations incorporate its variations. Real-time torque-and-drag data allow drillers to make more accurate predictions ahead of the bit. The well trajectory can be modified and performance of the BHA optimized by incorporating real-time data into modeling applications for calibration purposes.

In addition to core drilling applications, there is a need for integrated petrophysical analysis, casing and cementing design and temperature simulation. Interactive well log analysis is performed using the QLA Well Log Analysis module. The TDAS application includes an expert system that guides engineers to quickly design the lowest cost casing or tubing string from available inventory using an overall corporate design philosophy. The TDAS application also ensures that casing designs meet American Petroleum Institute (API) standards and International Organization for Standards (ISO) criteria. The CemCADE cementing software helps engineers plan successful cementing jobs from large-diameter surface casing to the deepest liner. Efficient scenario planning reduces waiting-on-cement time, avoids remedial cementing and ensures well safety.

For planning and drilling high-pressure, high-temperature (HPHT) wells, the Drilling Office system includes advanced simulators for gas kick and temperature modeling, critical aspects for success in these wells. The gas-kick simulator was the result of extensive research by Schlumberger and BP International Ltd. The project was initiated by the UK Health and Safety Executive (HSE) Offshore Safety Division following a number of well-control incidents on HPHT wells. Anadrl commercialized the resulting software as the SideKick program. Additional development was funded by the European Union Thermie program. The SideKick simulator models influxes, such as gas kicks, and can evaluate risk, design casing programs and plan procedures for controlling HPHT wells. The WEST program improves temperature predictions by engineers during drilling and cementing operations.

Complex wells constitute perhaps 20 to 30% of total wells drilled, and the benefits of teamwork and data sharing in these cases are obvious. Simpler wells can also be improved, however. A major benefit of integrated software and streamlined workflows can be achieved through an assembly-line approach to the simpler wells: the planning cycle is shortened, work becomes consistent and repeatable, productivity and cost savings increase dramatically. The work becomes less of an art and more of a streamlined operation with greater efficiency, simplicity and reliability. This shortens the drilling time-depth curve and ultimately reduces cost per barrel. By mastering simple, routine operations, engineers can then concentrate on improving processes, procedures and ways of operating (below).

For example, an engineer developing a mature oil field might realize that a single multilateral well is a cost-effective replacement for numerous vertical holes, or that it is possible to reduce the number of casing strings (see “Key Issues in Multilateral Technology,” page 14). The ability to study scenarios and improve on traditional approaches leads to reduced cost and risk in both simple and complicated situations.

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Companies that incorporate the Drilling Office system in their technical computing strategies will benefit from better data management, data integration and evolving computing standards. Integrated drilling software will improve planning and execution of drilling operations by reducing error and redundancy in the workflow. The companies can also expect to manage, use, integrate and understand their data better.

A major oil company has tested the Drilling Office tool suite and provided feedback to GeoQuest developers. The company is adopting the system as part of their internal computing initiative. Several E&P companies seek to buy rather than develop their own applications for general, mainstream needs and to develop proprietary software only for rare cases of unique needs. For such companies, the Drilling Office system will meet the need for both general drilling planning needs and specialized real-time calculations.

Looking Ahead
Integrated software for drilling planning and operations is a response to the need for products that support integrated, multidisciplinary workflows and today’s more exacting requirements for design and accurate placement of wells. Ideally, such software should follow the drilling process naturally, have a single database for each project and house applications that represent the best practices of the industry. Schlumberger will continue to enhance the capabilities of the Drilling Office system. In contrast to stand-alone applications that focus on individual tasks, the most powerful drilling software will integrate and unify tasks into smooth processes. As asset teams focus more on the overall process at hand, the value of corporate assets, that is, reserves in oil and gas fields, will be maximized (above).

As the use of integrated drilling software increases, members of project teams will better understand each other’s disciplines and roles through the new perspective of a shared database. By implementing the use of integrated software whose technical integrity has been clearly demonstrated at each stage of the workflow, companies can document their compliance with regulatory requirements, such as zonal isolation of water from hydrocarbons or shallow gas zones, more readily.

Just as integrated drilling software provides a seamless link back to geological and geophysical exploration applications, future functionality will include a similar link forward to the production phase that follows. A single database and an integrated suite of applications will simplify the exploration and production workflow from project conception to maturity.

—GMG