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Well Planning Quality Improved Using Cooperation between Drilling and Geosciences

Eric Cayeux, Roxar, Jean-Michel Genevois, TotalFinaElf, Stephan Crepin, TotalFinaElf, Sylvain Thibeau, TotalFinaElf

Abstract
To improve the quality of well planning and decrease the risks involved in drilling complex wells, E&P companies have been focusing during the last decade on collaborative work of asset team. A new workflow consisting in separating multidisciplinary feasibility evaluation from detailed engineering has now been used on several projects. This workflow decreases dramatically the necessary cycle time to plan a well since only those alternatives that are viable for all disciplines are going through detailed analysis.

The angle block of this method is the combination of a shared earth model with advanced three-dimensional visualisation techniques and quick, but precise evaluation tools. The use of constraints to define default values makes it simple to plan targets and wellbores only with 3D interactive graphic editing. Those constraints can themselves be relative to the structural geological model. Therefore the generated design is accurate enough to be trusted when used by the various evaluation functions. To assess the value and feasibility of a target/well solution, the asset team can use interactively drainable volume, wellbore position uncertainty, driller’s target, wellbore collision and drillstring mechanical calculations.

This approach has been used in different contexts for planning wells in an oil field in deep water western Africa and a gas field in Norway. For the field in the golf of Guinea, reservoir simulation has been used to define the location of horizontal drains. In Norway, an extended reach well has been planned using a 3D-reservoir model. The methodology has helped improve the overall understanding of the problem by sharing and explaining each other’s constraints, thus improving the well planning quality and reducing the design cycle time.

Introduction
Exploration and Production is synonymous with progress. New and always higher challenges demand new and always higher exploits, and all disciplines contribute to these achievements with advances in their respective field.

In drilling, for example, there has been spectacular progress in areas such as directional drilling, bit technology and trajectory control. In geology and geophysics, there have been leaps and bounds in logging technology, seismic treatment, reservoir characterization, and geostatistics. In addition, progress in all disciplines has been propelled by “external” advances ranging from always greater computing power to 3D visualization and virtual imaging.

This traditional pattern of progress in each discipline has been altered by new givens. Growing pressure from the financial side has radically increased in the space of ten years, putting a tight harness on spending. Efforts have become focused on cost-cutting and on higher, faster returns on investment. Teams have shrunk drastically. At the same time, Exploration and Production objectives have grown more ambitious, demanding better, faster improvements all the time. These demands focused notably on wells with complex geometry.

At TotalFinaElf, earlier experience in Libya had demonstrated the benefits of collective efforts in solving such complex problems. By combining expertise in reservoir engineering and subsurface geology and drilling, rapid and efficient solutions were found at the time with the limited means available. For processes and activities requiring the participation of several disciplines, it was clear that a synergy of know-how, with all teams and disciplines working hand-in-hand, offered promising potential for progress.

To take the “synergy of know-how” out of the realm of wishful thinking and tap this source of progress, the first requisite was thus appropriate software tools. As the market offered no adequate solutions, these tools needed to be built. That necessarily required external as well as internal expertise, with the active involvement of all the different disciplines concerned.

These considerations led to the launch of a project for the development of multidisciplinary software. In Phase 1, the two participants focused on well planning.
This choice was a logical first step for the development of this new concept. Well planning represents the point of convergence of efforts and studies by the various disciplines involved in Exploration and Production: geophysicists, geologists, reservoir engineers, and drilling engineers. And the more and more complex geometry of wells tackled today has turned well planning into an extraordinarily heavy challenge, difficult to master with a mono-disciplinary approach. The traditional compartmentalized structure found in oil companies lacks efficiency, resulting in iterative processes that are unproductive and costly in money and time.

At the very start of the project, it became apparent that several hurdles would have to be cleared:
- Geologists and geophysicists were accustomed to the Unix environment, whereas reservoir and drilling engineers were more PC-minded.
- Used to dealing with large amounts of data, geologists, geophysicists and reservoir engineers approached problems with global vision, while drilling engineers focused on figures and numbers.
- In 3D visualization techniques, drilling engineers were still, quite literally, “in the dark”.

These factors needed to be taken into account in developing the multidisciplinary platform, and the chosen components had to be in line with TotalFinaElf’s long-term strategy. Management rapidly validated and supported the choices made, and soon after the first a multidisciplinary team was set up with representatives from all the disciplines involved in well planning.

In the early stages of the project, we concentrated on traditional workflows and new ways of well planning. The advantages of working directly in the geomodeler or in a seismic cube soon became apparent, and with all disciplines contributing their expertise and best efforts, the first synergies were achieved very rapidly. Here are two examples, among many others:
- For drilling engineers, well collision avoidance meant endless lists of numbers that offered little help in pinpointing problems. Their only option had always been trial and error. Thanks to the visual experience gained from the other disciplines, it was established that 3D offered much more effective solutions, simulating a camera making its way downhole inside the traffic of neighbouring wells.
- For geologists and reservoir engineers, geomodels started and stopped at the reservoir: overburden was of no concern. Knowing how difficult it can be to reach the target, drilling engineers considered that it was particularly important to include data on these formations, notably to highlight drilling hazards. For geologists, the possibility to visualize trajectory uncertainties immediately was also a definitive plus, never envisaged before. Integrating information above the reservoir in the geomodel could also help to reduce geological uncertainties, further optimizing the representation. Based on this joint Roxar and TFE project commercial software has been developed by Roxar. The functionality of this software is described below and this software has been utilized in the field cases presented in this paper.

### Multi-disciplinary Well Design

When a multi-disciplinary team is designing a target or a well, the members of the team expect to spend most of their time in evaluating the various conceptual solutions and not being struggling with details. Therefore each steps of the design has to be streamlined as much as possible to increase the efficiency of the process. In addition some members may have little or limited knowledge about the concepts used by the other disciplines. As the old adage says, “a drawing is worth a thousand words”, so to facilitate communication it is useful using as much as possible interactive graphics. Creating a geometrical path inside the reservoir or to reach a pay zone is of little interest if it cannot be evaluated in terms of its value and its feasibility.

So a system to assist asset teamwork shall respect the following requirements. First of all, the user shall have access to a whole range of graphical functions for both representing the data and positioning the geometric elements of the design using intuitive interactions. Second, the generation of target and well tracks shall be completely automatic to avoid interaction with numerical inputs. Last, quick but precise evaluation functions shall be available to validate the feasibility of the design.

Even though, each discipline has its own requirements on the geometry of the path, drilling is, in the last resource, the most constraining one, both in terms of geometric outlook and feasibility evaluation. Therefore a lot of emphasis has been put to include standard drilling practices at all stages of the design process.

### Target Design

Designing a target is the stage that requires the most input from all disciplines. The search for a favorable drainage area will not be described here since there is almost many strategies as there are hydrocarbon reservoirs. But when it comes to the constraints that a target axis shall respect, they can be classified in 3 categories.

The first one is related to the direction of the target. There are three possibilities: no constraint on the penetration direction, the target azimuth is imposed but no turn is acceptable, or the well shall follow a channel and turning inside the reservoir is possible. When no constraint on the penetration direction is imposed, the well path direction will define the shape and dimension of the target axis. In that case, the target axis is constructed using the entry position and an extrapolation strategy. The geological context can impose a general direction but drilling conditions (like buckling problems in sliding mode) may impose that no turn is accepted inside the reservoir. Even if drilling can tolerate azimuth changes, it is in most cases necessary to limit the orienting sections to places which often shall be as close as possible to the start of the target. To fulfill all those requirements, the target axis is built using target control points (Fig. 1). Those
points are capturing a particular position inside the reservoir model and possibly a direction (i.e. an inclination and an azimuth). The curves linking the control points are circular arcs. It is important to use curves with a constant curvature to mimic in an acceptable fashion the drilling process. When the inclination and azimuth at a control point are not imposed, then a unique circular arc can link the control points. But if the user is fixing the tangent at a control point then a double circular arc is used to connect the previous control point. The particularity of the double arc is to use a constant curvature, in order to be drilled in the simplest manner. An extrapolation can be applied after the last control point. The extrapolation is using a general concept of relative depth definition. The so-called “relative depth” definition can be used in two ways; either it is an absolute value like a TVD or an extrapolation length, or it is defined relatively to the intersection with a horizon or a formation top. When it is relative to an intersection, it can either be as a variation of depth or length. The picking of the target control points is always done in a 3D context to secure a good understanding of the environment. Two major techniques are available. One consists in recording the position of target control points using a 3D cursor. This cursor can be moved in the 3D space with mouse interaction, then chosen positions can be recorded to be part of the target axis. The alternative technique consists in picking directly on a surface or a volume. Using movable and orientable cross-sections, it is possible to pick targets in a given direction, insuring those turn constraints that can be imposed on a target axis. Along hole and lateral fences can be associated with the target axis and the control points to display the value of a 3D parameter or the intersection with the structural model. The free cross-sections and the target axis fences help working in a 2D plane still having a full understanding of the 3D context. In addition, alignment function exists to force straight lines or turn conditions even though change of azimuth is possible.

The second category of constraints is associated with curvature limits. To avoid defining unrealistic target axes, dogleg severity (DLS) limits can be applied while constructing the target. The DLS along the target axis is compared continuously with the maximum authorized. Visual warnings are given to the user as soon as the curvature limits are no longer respected.

The third set of constraints is linked to vertical distance to formation tops or fluid contacts. It is often desirable to set the target axis at a given vertical distance to the water-oil contact or the gas-oil contact to manage correctly water or gas coning. Therefore one can define vertical distance constraints relative to formation tops or surfaces. When those constraints are defined, it is possible to snap the control points relatively to those limits. If both an upper and lower limits are defined then the target control points are placed as a proportion of the vertical distance between the two surfaces.

By working directly on the target axis and using as much as possible the drilling constraints simultaneously with all the information available on the earth model, it is possible to generate a fairly realistic representation of the well inside the reservoir.

**Target Boundary Definition.** The target axis represents the optimum placement of the well inside the reservoir. Since it is not likely that the final well track will be exactly on top of that ideal curve, it is therefore important to capture the acceptable limits for the final well position. A boundary can be associated to each control points in a perpendicular plane to the target axis. The shape of the boundary can either be a rectangle or an ellipse. A morphing algorithm is used to connect the boundary limits at each control points into a tube that follows the target axis (Fig.2). The boundary limits are adjusted graphically compare to the available information in the earth model (seismic data, structural model, volumetric petrophysical properties or reservoir simulation results).

**Target Evaluation.** A first method to evaluate the value of a target consists in calculating the hydrocarbon volume that is associated with the target axis. The cell connectivity and geometric filters can be used to estimate both bulk and fluid volumes.

For time dependent evaluation, a streamline simulator, a near wellbore simulator or full field simulation can be used. The system can generate completion intervals based on intersection with formation tops or fluid contacts and parameter filters. One interesting feature of the near wellbore simulator is to automatically upscale the region outside the well and fault areas, making it possible to work with a fully detailed geological model.

**Well Path Design.** Traditionally, systems used to generate planned trajectories have been using two types of approach. The first one can be called “section-based”. One chooses amongst a certain number of predefined sections or profile types and combined them to reach a target. The second approach may be called “the spreadsheet method”. A table describing the different sections necessary to reach the target can be partially filled, then the system calculates the remaining values. Both methodologies require a substantial amount of input and a deep knowledge of drilling practices. It appears that none of them would be suitable for designing quickly a well plan. It would rather be interesting that the well path would be generated directly based on normal drilling practices and acceptable drilling constraints. The drilling practices are tightly related to the drilling program, so the constraints to be respected have to be associated with each drilling phase. Taking advantage of the earth model definition, each drilling phase can be defined relatively to formation tops. Therefore, the complete drilling program is readjusted according to both the relative position of the target, to the tie in point of the well and the formations in the overburden (Fig.3). To generate the well path, the system is using an iterative procedure, which include a new constraint at each step, then readjusting the drilling program according to the intersection with formation tops. When all constraints have been included or the inclusion of a constraint fails then the procedure stops and the result is displayed. The actual solving of the well path is done using a
generic solver. The solver is using the following principle: if the starting point is fully defined (i.e., its position and tangent are known) and if there are n sections to reach the target entry, only 3n parameters are needed to complete the well profile. Those parameters can be chosen amongst the length of a section, the inclination, the azimuth, the TVD, the northing, the easting, the curvature or the toolface. It is not necessary to have exactly 3 parameters per section, so if a section has less than 3 parameters, then another section shall have more than 3 as long as the total number is 3 times the number of sections. This gives a great freedom for defining the well profile. The difficulty is coming with incompatible parameters or parameter that are linked together. In those cases, the resolution will give either no or an infinite number of solutions. Hopefully, the well path generator is using many heuristics to avoid those situations, thus avoiding those types of failures.

Even though the generation of the well path is completely automatic, the result is fairly detailed and in addition it fits adequately with the earth model. A second benefit is that the shape of the well is not predefined at the start, it is rather a consequence of the relative position of the tie in point, the target, the drilling program and its constraints. So changing the slot allocation or changing the coordinates of the template location results in a complete replanning of all the wells, including sidetracks, possibly changing dramatically the shape of each individual wellbore. This gives the opportunity to do platform position optimization in a very broad sense.

Well Path Evaluation. The uncertainty on the wellbore position can be evaluated using a surveying program. This uncertainty can be used to evaluate the proximity to geological features. For instance, the system can derive a driller’s target out of the geological target boundaries. The idea of a driller’s target volume is due to John Thorogood. If a well is landed exactly on the limit of a geological target boundary, there is a large probability that the well will be outside the limits because of the uncertainty on the wellbore position. Therefore, the drilling engineer needs to make sure the well is landed in a sub-volume of the geological target boundary, which is reduced by the size of wellbore uncertainty (Fig.2).

Another application of the wellbore position uncertainty, is collision detection. The system provides a true 3D scanning of a well path for proximity evaluation. The comparison can be made to other wells or to geological features like faults. In fact, the anti-collision scanning is very similar to a travelling cylinder apart from the fact that it is an interactive 3D scanning instead of being a 2D polar plot (Fig.4). Using the full fledge 3D visualisation, it is much easier to understand collision situations. The user can add extra control points to nudge the well and steer it outside the problematic zone. In that way, only using 3D graphic interaction, collision avoidance can be achieved. Similarly, it is possible to force the path of the well at proximity to faults, either by changing the penetration angle or bypassing them.

Finally it is possible to run drill-string mechanical evaluations. The drilling program can include the description of standard bottom hole assemblies (BHA) as well as the typical running conditions (like weight on bit, friction information, etc.). Using those inputs, the system calculates torque, drag forces and buckling conditions for each of the drilling phase and for each of the drilling conditions (running in, pooling out of hole, drilling rotary, oriented drilling, working pipes or running casing). Summary results are displayed in terms of alarms (Fig.5). In case of alarms, one can look closer to the results of all calculations to understand the reason of the problem and change the drill-string configuration or the planned trajectory. The system is using stiffness for the torque and drag calculations as well as a complete triaxial analysis. Nevertheless, this is not the intention to go for a very detailed drilling engineering at that stage. The important aspect of the drill-string mechanical evaluation is to quickly get an understanding of the drillability of the well. In the future, the system will also have access to drilling hydraulic calculations and wellbore stability evaluations.

Complex Targets and Wells. Targets can be grouped into laterals. In that manner, multi-lateral wells can be generated with their necessary sidetracks. Similarly, to deal with multi-layered reservoir, it is possible to group targets in sequence. In that case, the wellbore will pass through the different target axes in the order defined by the target group.

Byggve field case
Byggve field and well objectives. Byggve is a gas field located in Production License 102 in the Norwegian Continental Shelf. It was discovered in 1990 by well 25/5-4. The reservoir lies in the Brent, Upper Jurassic formation. The Byggve structure is a North-South elongated horst, 15 km South of the Froy platform.

The field is understood as made of three main segments, out of which two are gas bearing (Fig.6):

- Segment ② is the shallowest segment, and as such is expected to contain two thirds of the producible gas;
- Segment ① was the one drilled by the exploration well, and hence is gas proven.

The gas volumes are planned to be produced through a depletion scheme, with a single gas producer. In order to optimize the gas recovery and face a possible disconnection between segments ① and ②, it was decided to enter the reservoir in segment ②, and extend the well into segment ①.

Initial well planning. The initial well planning was performed by:

- Defining well target coordinates (entry point in the reservoir in ② and heel of the well in ①) in order to optimize gas production from a flow model (Eclipse-100 flow simulator);
- Enter the coordinates in the RMSwellplan software to define the well trajectory.
As the well was entering the top of the reservoir with a high deviation, it was decided to include a Pilot Hole in the well design in order to account for possible uncertainty in the depth of the top of the reservoir. As it can be noted from figure 8:

- the field is very faulted whereas the flow structural grid:
  - is very smooth;
  - is not oriented parallel to the fault orientation; and
  - does not include the fault geometry above the reservoir.
- the well trajectory is very close to a fault within 🥇;

Following this preliminary well definition, it was decided to optimize the well target and trajectories using a detailed geomodel.

Well target definition in a Geomodel. A geomodel was built from existing seismic interpretation of main horizons and fault sticks.

The initial well trajectory (red) and well target (blue) are displayed on the base reservoir with two key boarding faults on figure 8.

It can be seen from this figure that:

- the well hits a fault (in blue) before entering the reservoir;
- the well targets crosses the base of the reservoir (in gray), which was not planned for; and
- the well toe ends up very close to the field main fault (in yellow).

It was possible to optimize the well target in order to be located in a safe position in the structural model. The target control points are directly edited in the structural model, using a 3D cursor (dragger). In figure 9, the updated target (in red) is displayed next to the initial target (in blue).

Input of drilling constraints. In order to build the well trajectory from the target,

- a pilot hole target was defined aligned with the horizontal drain;
- the subsea position was derived from the pilot hole target;
- the drilling phases were defined, for both the pilot and the horizontal branch:
  - drill string parameters;
  - casing diameters and shoe positions;
  - liner suspension depth and diameter as a last phase of the horizontal drain.

Specific geometric constraints (maximum DLS) were defined through this process, in order to ensure the drillability of the well.

Oil field in West Africa deep offshore
RMSwellplan has been used very efficiently on a West Africa deep-offshore development project.

The purpose was to check the feasibility of different wells development scenarios. The field is made of two main and independent channels that are not over-lapped. Each channel is made of different layers, whose vertical dynamic connection was uncertain. Sub-marine or platform development could be considered. Each sub-marine case is composed of clusters along a production line for the production wells and single wellheads along the injection line for the injector wells. For the platform case, the same platform was to be considered located in the middle of the two channels. Moreover, one of the channels was very faulted with much uncertainty on faults sealing, and two reservoir draining scenario had to be considered. The first one with a well for each compartment, connecting the different vertical layers and the second one with fault crossing wavy wells. The first step of the project was to check the drilling feasibility of each scenario before going further and considering them for any economical comparison. Looking at the complexity of the reservoir, at the number of wells, up to 60 wells all together, at 3D complex wells including wavy wells, it was quite impossible to consider to work with an usual workflow and usual drilling engineering tools without spending weeks to get a first result: the reservoir engineer proposing a target designed on his reservoir model, checking with the geophysicist that the target was crossing the good markers on the seismic HR3D, the driller engineering a well for each targets. One can imagine how many forth and back exchanges between the geoscientists and the drillers would be needed before finding a compromise for each well. More over to design a 3D snaky well without a 3D tools environment would be a challenge.

It was decided to use RMSwellplan. The tool allowed gathering on the same workstation geoscientists and drillers. In order to be able to work with a small team of 3 to 5 collaborators, a geovision room was used.

An earth model was available and the “net to gross” parameter has been used for the placement of the targets. We have also imported the 3DHR seismic cube with the “amplitude” parameter: after transforming the time-seismic to depth-seismic using the in-house tool Sismage, the seismic cube was imported in a segy compatible format. We had also available faults representations, different reference horizons as the mud-line surface, top and bottom of the reservoirs.

Prior to starting work on the geovision room, some preparations were done in order to improve the efficiency of the work session. For no-wavy wells, the geoscientists proposed a first rough target design, (one producer and one injector for each compartment) with heel and toe targets co-ordinates. All segment-targets were reported in a spreadsheet and a horizontal view was printed with contour mud lines. By using this view, a candidate pattern for production and injection lines with clusters (well heads) was established. This was done both for the sub-marine case and the platform case. As a result of this exercise, preliminary co-ordinates and water-depth for clusters and wellheads were established (see Fig. 10).
The next step has been to input all the targets (heel and toe control points) in the RMSwellplan system as well as the clusters, wellheads and plate-form coordinates. Only the wavy targets were not pre-designed this way because of their complexity. It was compulsory to work in the 3D environment at the very beginning.

Once targets and wellheads were entered, a first wellpath was designed using the automatic algorithm of RMSwellplan. The generated well paths were connecting the target to the tie in points (clusters or wellheads) using the different drilling constraints set by the driller. The constraint used were: kick-off point at 600 meters under the mudline surface, 1°/10 meters maximum DLS, end of the different drilling phases referred to TVD, MD or Horizons. Friction factors have also been entered for each phase in open hole and in cased hole, for the drilling string and for the casing or completion string.

At this stage we were able to gather the different protagonists in the geovision room to start the integrated teamwork. We have had a look at each well, using 3D views (Fig.11) but also 2D views or wellpath tables which are some times more “representative”. When one was not considered drillable, (too high DLS, too much azimuth change etc…), the reservoir engineer proposed some modifications to the target in order to improve the general shape of the wellpath according to the driller recommendation, keeping an acceptable target location in the reservoir, (good net to gross ratio, cross-connection of different layers, compartment drainage etc…). Thanks to the reservoir model 3D views, to the different cross-sections views (Fig.11) we could display, it has been quite easy to find some new acceptable targets following their reservoir constraints and the drillers constraints. We have kept track of the different versions of the target. Before endorsing the target and the well, we have used the seismic display to check the target location with regard to amplitude makers (Fig.12). Again the use of section views with azimuth flexibility thanks to the dragger has been very powerful for such exercise, in addition to the normal sections. Indeed the normal section views on East-West or North-South following the UTM reference box were not always the most suitable because of the general heading of the reservoir.

When we did not succeed to get an acceptable target and wellpath, or in order to reduce the well total drilled length or the azimuth change, we played on the cluster or well-head location, the system being able to replan all the connected wells.

Using an integrated platform and a geovision room, we have succeeded to reduce the time of this study very significantly, if ever any result could have been obtained for the wavy wells with traditional tools.

Conclusions
1. Using 3D graphic for conveying information in between disciplines is the first and minimum step toward a good teamwork cooperation.
2. Having access to quick but precise evaluation functions for each discipline is a key factor for improving the efficiency of an asset team.
3. Including drilling requirements at all stages of the target and well design process is necessary to get viable solutions and streamline the iterations between the geoscience requirements and the drilling limitations.
4. Using constraints relative to formation tops or other events to generate target or well geometry is a fundamental feature to ease 3D graphic interaction.
5. This methodology has been successfully used for pre-project work and for detailed well planning.

The result from this development project is now offered as a commercial software product by Roxar.

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References

Appendix
Fig.1: Target control points define a target axis. Both the position and the tangent at the control points is influencing the shape of the curve.

Fig.2: Target defined in a fault block. The target geological boundaries are semi-transparent, while the driller’s target is in white.

Fig.3: The well path is generated using a drilling program that contains constraints to be respected and which is relative to formation tops.

Fig.4: Collision scanning at 1960mMD (RKB), Incl 90deg, Az 9deg.
Fig. 5: Along hole torque excess in top hole section for 8"1/2 drill-string in drilling with rotation.

Fig. 6: Main segments of the field (3D view from south – Top of the reservoir)

Fig. 7: Pilot (blue) and horizontal drain (red) - 3D view from SW with segment ⋄ only

Fig. 8: Initial well trajectory and target superimposed with structural elements (SW view)
Fig. 9: initial target (in blue) and updated target (in red) in a structurally safe position (from SW).

Fig. 10: mudline clusters & wellheads pattern with targets & wells top overview.

Fig. 11: initial target with a difficult well to drill & target modified with a simpler wellpath.

Fig. 12: reservoir seismic with well and target display.