Well Site Selection Algorithm Considering Geologic, Engineering and Economic Constraints: A Progress Report

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Abstract

Well placement decisions must be made in the face of many geological, engineering and economical constraints. Some of these goals include (1) maximum intersection of connected regions of high quality reservoir, (2) avoidance of fluid contacts that could cause early breakthrough and reduced productivity, (3) compliance with physical drilling constraints such as curvature and maximum distance, and (3) placement in proximity to platform locations. We consider well placement subject to such complex constraints and accounting for geological uncertainty quantified by multiple geostatistical realizations.

An iterative algorithm is proposed for well placement subject to multiple constraints and "optimality" relative to uncertainty in the reservoir model. Preliminary results were presented in CCG Report One (1999). Incremental results are presented this year due to coursework.

Introduction

Placement of wells is an important problem that depends to a large extent on reservoir geometry and continuity. Since the reservoir is never known exactly, geostatistical realizations are being increasingly used to represent reservoir heterogeneity and uncertainty. There have been a number of attempts to use geostatistical models for well placement.

In 1995, Goggin et al. (1) reported a well-position optimization method based on statistics. Well planning using a deterministic 3D model or an inverted seismic data volume during the drilling of a horizontal well has been performed in a number of places, see for example Badgett et al. (2). Gutteridge et al.(3) takes the application of 3D geological reservoir models forward from basic well planning, to a screening and ranking of multiple well path options based on quality of connection to volumes of net sand and on instantaneous productivity index. Quality factor maps are used in their research as potential well positions, and then well paths are ranked in the order to obtain optimal well sites. They takes advantages of what they called 'shared earth model', the model generated by latest 3D modeling packages.

Also in 1996, D. Seifert (5) generated geological 3-D stochastic reservoir models by integrating reservoir specific and outcrop analogue data into a hybrid deterministic-stochastic model. The model provides the basis for determination of the optimum well trajectories and subsequent risking of their success. In his work, both horizontal wells and inclined wells are evaluated over multiple realizations.

"Integer Programming Optimization" was also applied as an automatic well selection method by S. Vasantharajan et al. (4). In his work, quality map is used as input to the well site selection.

No preious work considers the many restrictions on well placement. In this paper, an integrated optimization algorithm is presented to take care of the parameters encountered both in exploration and development stage, such as the geo-objects a well trajectory may intersect, connected volume, various lithologic properties of reservoir rock like porosity, permeability and geologic structure and structural position. Also, well path sinuosity is captured by curvature of the well path.

We propose an iterative algorithm that can simultaneously consider multiple constraints in component objective functions. They must be combined into a single objective function to be minimized. The weighting of the different components will consider the work of Deutsch (6). We present progress to date.

Grid Topology

A 3-D reservoir model can be represented by an areal grid with nx *cells along* x *direction and* ny *cells in the* y *direction. The cell size is* dx *and* dy *in the* x *and* y *directions, respectively. We consider a constant* dx *and* dy*, but this could easily be relaxed. In order to account for the depth of the reservoir, we employ a variable depth array* $D(i,j), i = 1...nx,\ j = 1...ny$*, see Figures 1 and 2.*

Well Path definition

A well path is a 1-D trajectory defined by a sequential set of N *coordinate locations* $\{(x_i, y_i, z_i), i = 1, ...N\}$*, e.g., see Figure 3. The trajectory between the* N *control points may be taken as linear or following a spline curve. The control points could be vertical, inclined, or almost horizontal, see Figure 4.*

Geo-object (Flow Unit) Calculation

A reservoir consists of connected regions, which we wish to produce with the fewest number of wells in the best locations. The different connected regions in a reservoir are called "geo-objects" or flow units. Each geo-object is a collection of net (reservoir quality) cells that are connected together but disconnected from other geo-objects. Figure 5 illustrates three geo-objects, while the outside cells are non-reservoir quality. Geo-objects are normally sorted according to their sizes, where geo-object 1 is the largest, 2 is the second largest and so on. Details on calculation of geo-object connectivity can be found in Deutsch (4). The program for geo-object calculation has been integrated into the well selection program.

Connected Volume to Well Locations

The connected volume (CV) to a well location represents the reservoir volume that can be drained by a well, that is, the reservoir volume that is reservoir quality and connected to the

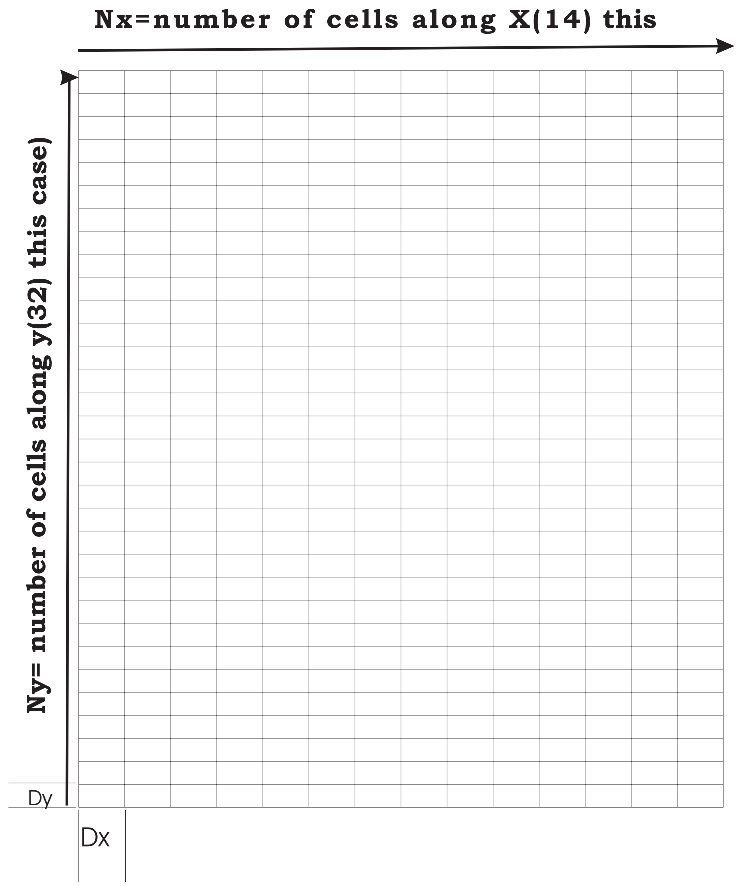

Figure 1: Plan view of grid system.

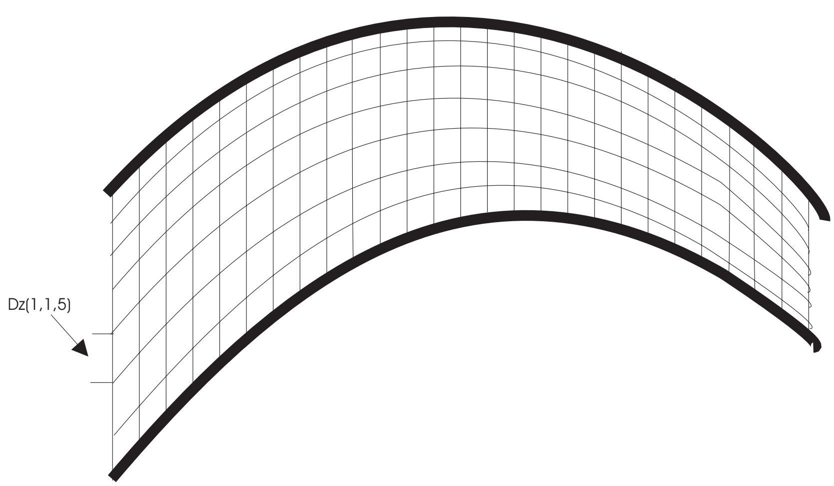

Figure 2: Definition of Dzs.

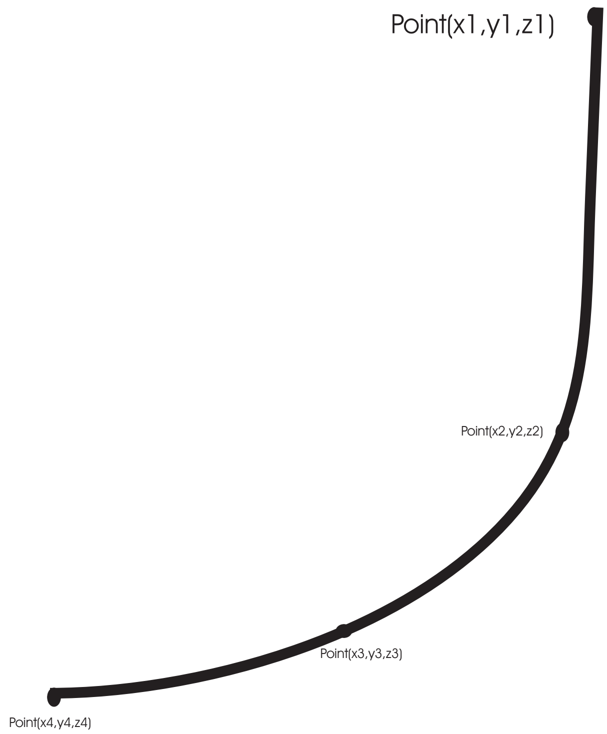

Figure 3: Definition of a well path with 4 control points.

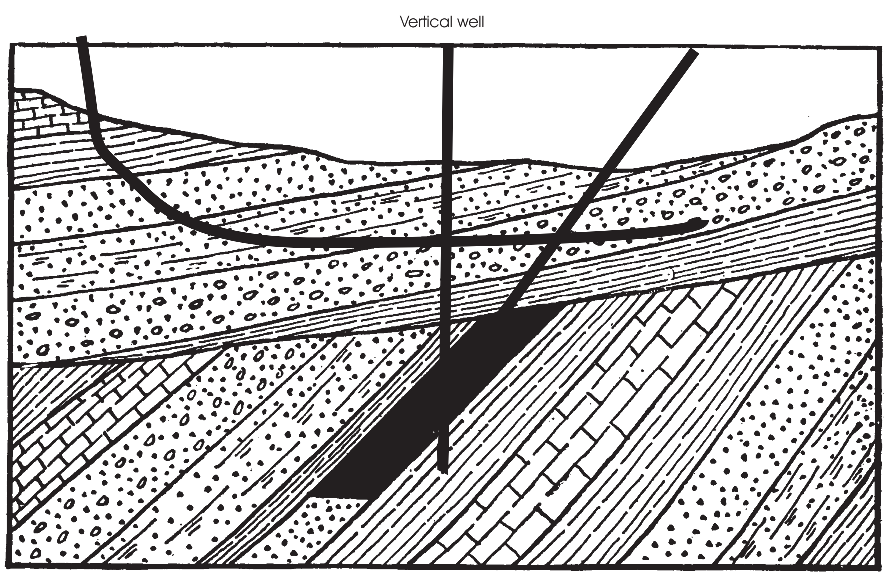

Figure 4: Three well types: horizontal, vertical and deviated wells

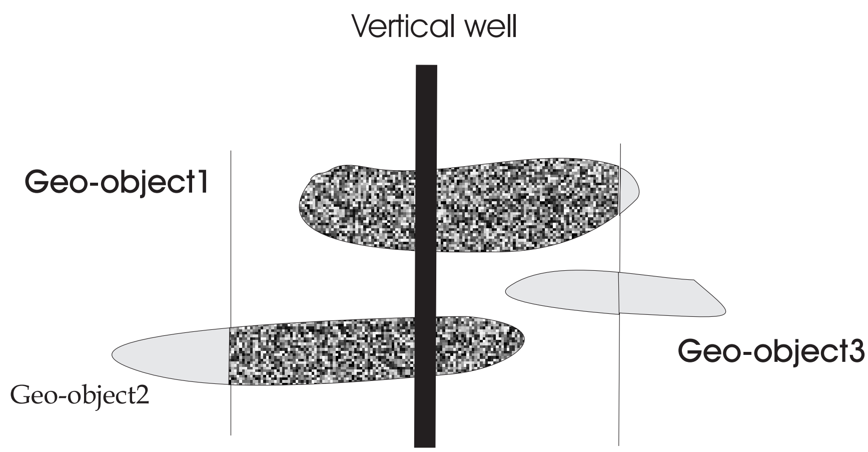

Figure 5: Schematic illustration of geo-objects and connected volume to a well location. The dashed lines represent the drainage radius.

well location and within the drainage radius of the well. The connected volume depends on the geo- objects intersected by the well and their distribution within the drainage radius. In presence of multiple geostatistical realizations, the average or expected value of the connected volume for a well location may be determined.

Let Ω represent the set of all cells within the drainage radius of the well. The indicator variable $i(u, u_w)$ represents the probability of a location u being connected to the well location, that is,

$$i(u, u_w) = \begin{cases} 1, \textit{if location } u \textit{ is connected to well at location } u_w, \\ \qquad \textit{and } u \textit{ not connected to another well} \\ 0, \textit{otherwise} \end{cases} \tag{1}$$

The connected volume for well u_w is the indicator-weighted sum of all cells in the drainage radius,

$$CV_w = V_c \sum_{u \in \Omega} i(u; u_w), \;\; \textit{where } V_c \textit{ is volume of a cell} \tag{2}$$

Note that we could easily multiply this term by the porosity of each cell to get a true pore volume. A single well can intersect several geo-objects simultaneously. The connected volume is the sum of all the cell volume that fit the criteria specified above.

For multiple well configurations, we need to calculate the total CV of all the wells, the cumulative connected volume (CCV). It can be expressed in the form of object function *component:*

$$O_{CV} = \sum_{w=1}^{n_w} CV_w = V_c \sum_{w=1}^{n_w} \sum_{u \in \Omega} i(u; u_w), n_w is\ number\ of\ wells \tag{3}$$

In combination with other objective components, O_{CV} can be used as a criteria for well positioning. For the same number of wells, we would prefer the well configuration with the greatest O_{CV}.

The simplest case is when only one well location must be chosen. The O_{CV} for all candidate locations and possible well trajectories can be calculated and, then, the well trajectory is set to the one with the maximum connected volume. This procedure could be repeated sequentially to place multiple wells; however, this will not in general, achieve the maximum O_{CV}. The number of combinations to consider is very large, which makes the multiple-well case difficult.

Geologic Structures and Structural Position

Geologic structure influences oil and gas accumulation and drainage in many ways and must be taken into account. The location of the fluid contacts relative to well locations is important.

The facies, porosity, and permeability vary widely and must be given careful consideration in any study of well placement. Production rates are higher in highly porous reservoir rocks. Permeability is critical, for if the resistance to flow is high, the rate of recovery will be slow. Wells in "tight" formations may quickly reach an uneconomic rate of production.

Sinuosity

Curvature ξ is defined as the change in angle of the tangent divided by the change in arc length:

$$\xi = lim \left| \frac{\Delta t}{\widehat{MN}} \right| = \left| \frac{dt}{ds} \right| = |t'| \tag{4}$$

Δt is the change in angle of the two successive tangents t and Δt on a space curve. ds is the change of the arc length from point (x_N, y_N, z_N) to $(x_{N+1}, y_{N+1}, z_{N+1})$. The parametric formula to t can be described as follows,

$$\xi = \sqrt{x''^2 + y''^2 + z''^2}\ (sasit'sparameter) \tag{5}$$

where, $x'' = d^2x/ds^2\ y'' = d^2y/ds^2\ z'' = d^2z/ds^2$

The above equations are defined in the continuous domain, discredited versions of the partial derivatives must be found before implementation is possible. Using the forward and backward definitions of the derivative, the following difference functions can be used in place of the partial derivatives:

$$X' \approx \frac{X_{N+1} - X_{N-1}}{2\Delta s}$$

$$Y' \approx \frac{Y_{N+1} - Y_{N-1}}{2\Delta s}$$

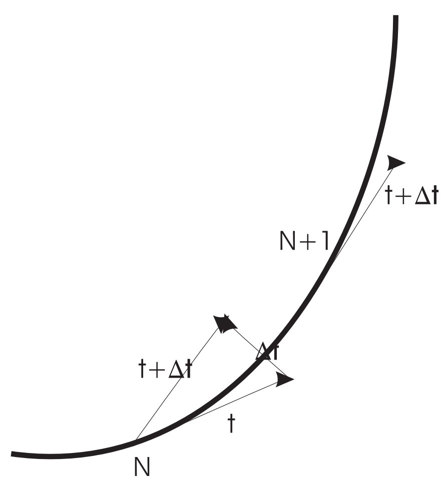

Figure 6: Definition of curvature

$$Z' \approx \frac{Z_{N+1} - Z_{N-1}}{2\Delta s}$$

$$X'' \approx \frac{X_{N+1} - X_N - X_{N-1}}{\Delta s^2}, \;\; Y'' \approx \frac{Y_{N+1} - Y_N - Y_{N-1}}{\Delta s^2} Z'' \approx \frac{Z_{N+1} - Z_N - Z_{N-1}}{\Delta s^2}$$

The units for curvature is degree/length units, where the magnitude depends on the length quantity.

Fluid contacts

The closeness of the well to the oil water contactmay be penalizedby $O_{WC} = m_1 - l_{wc}$, *where,* $l_{wc} = \sqrt{(x_w - x_c)^2 + (y_w - y_c)^2 + (z_w - z_c)^2}$, w *is the closest point on the well path to the fluid contact plane,* c *is the fluid contact plane, and* m_1 *is a constant associated with distance from well trajectory to fluid contact. Gas oil contact restriction could be defined similarly.*

Platforms / Drilling Pads

Sometimes the well sites are restricted to be drilled from central locations such as platforms or drilling pads. The optimization program should have the ability to account for this constraint.

Objective Function

All objective function components are combined. The method introduced by Deutsch (5) is used to combine the effects of different restrictions. The final objective function O *is made up of the weighted sum of* C *components:* $O = \sum_{i=1}^{c} w_i O_i$ *where* w_i *and* O_i *are the weights and components objective functions.*

Notice that each component objective function O_C *could be expressed in widely different units of measurement. Equal weighting causes the component with the largest magnitude to dominated the global objective function. All decisions of whether to accept or reject a perturbation are based on the change to the objective function,*

$$\Delta O = O_{new} - O_{old}$$

with

$$\Delta\, O = \sum_{c=1}^{c} w_c (O_{cnew} - O_{cold}) = \sum_{c=1}^{c} w_c \Delta O_c$$

To make each component contribute equally to the change in the objective function ΔO*,weights* $w_c, c = 1, ..., C$*.This is to say, each weight* w_c *is made inversely proportional to the average change in absolute value of its component function:*

$$W_c = \frac{1}{|\Delta O_c|}, c = 1, ..., C$$

Finally, the overall objective function is finally written as,

$$O = \frac{1}{O^{(0)}} \cdot \sum_{c=1}^{c} w_c O_c$$

The initial value $O^{(0)}$ is introduced to make sure the object function starts at 1.0 and a dimensionless annealing schedule may be used.

Methodology

Features of our problem formulation:

1. *Choose number of wells to be optimized, note that wells can be combinations of deviated wells and horizontal wells etc.*

2. *Select initial locations and well path categories. Well path categories are horizontal, deviated and vertical wells. Clustering wells are handled by selecting initial location within one preset drilling spot.*

3. *Object function: Our objective here is a combination maximum of the following objective functions:*

   - *Maximize connected volume* O_{cv}
   - *Minimize penalty associated with closeness to fluid contacts* $\sum_{i=1}^{n} O_{fc_i}$*,where n is the number of*
   - *Minimize penalty associated with interactive between wells* O_{dp}.
   - *Other user defined restrictions and objectives.*

4. *The initial O_{all} is calculated;*

5. *Perturbation Mechanism: randomly choose a well and modify the well trajectory by randomly choosing the following options:*

   - *Collar translate: defined as randomly select a distance for the well path $(\Delta x, \Delta y)$ within preset scope and shift the whole well trajectory.*
   - *rotate: randomly choose a control point in the trajectory and randomly choose an angle with degree $(\Delta\alpha, \Delta\beta, \Delta\gamma)$ and rotate the trajectory.*
   - *change path:randomly choose a control point on the trajectory and randomly choose a shifting distance donated by $(\Delta x, \Delta y, \Delta z)$. Note: all the shifting distance and angles are restricted by curvature preset in advance.*

6. *Recalculate the over all objective function of the new configuration;*

7. *Decision rule: the whole procedure will continue once the objective function isn't changing much*

   where O_{all_cur} is the current value of objective function, O_{all_pre} is the value it previous accepted and O_{tol} is the tolerance of objective function we set in advance.

Flow chart

A flow chart based on the above methodology is stated below.

References

1. *Deutsch, C. and Journel, 1992, GSLIB: Geostatistical software Library and User's Guide, Oxford University Press, New York, 340 p.*

2. *Deutsch, C., 1997, Fortran Programs for Calculating Connectivity of 3-D Numerical Models and for Ranking Multiple Realizations, Computer and Geoscience.*

3. *Gutteridge, P. A. and Gawith, D. E. 1996, "Connected Volume Calibration for Well Path Ranking", SPE Paper Number 35503 presented at the European 3-D Reservoir Modeling conference, Stavanger, Norway, pp. 197-206.*

4. *Vasantharajan, S. and Cullick,A. S., 1995, "WELL SITE SELECTION USING INTEGER PROGRAMMING OPTIMIZATION", presented at the European 3-D Reservoir Modeling conferences, Stavanger, Norway.*

5. *Deutsch, C. and Cockerham, 1994, "Practical Considerations in the Application of Simulated Annealing to Stochastic Simulation", Mathematical Geology, Vol. 26, No. 1, 1994.*

6. *Seifert D., Lewis J.J.M.,et al, 1996,"Well Placement Optimization and Risking Using 3-D Stochastic Reservoir Modeling Techniques", SPE Paper Number 35520.*

7. *David. J. Goggin, June Gidman and Steve E. Ross," Optimizing Horizontal Well Locations Using 3-D, Scaled-Up Geostatistical Reservoir Models", SPE Paper Number 30570.*

8. *C. V. Deutsch and /s. Srinivasan. Improved Reservoir Management Through Ranking Stochastic Reservoir Models. In SPE/DOE Tenth Symposium on Improved Oil Recovery, Tulsa, OK, pages 105-113, Washington, DC, April 1996. Society of Petroleum Engineers. SPE Paper number 35411.*

9. *S. Kirkpatrick, C. D. Gelatt Jr., and M. P. Vecchi. Optimizaiton by Simulated Annealing. Science, 220(4598):671-680, May 1983.*

10. *W. H. Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling. Numerical Recipes. Cambridge Univerisity Press, New York, 1986.*

11. *N. Saad, V. Maroongroge, and C. T. Kalkomey. Ranking geostatistical models using tracer production data. In European 3-D Reserfvoir Modeling Conference, Stavanger, Norway, April 1996. Society of Petroleum Engineers. SPE Paper Number 35494.*

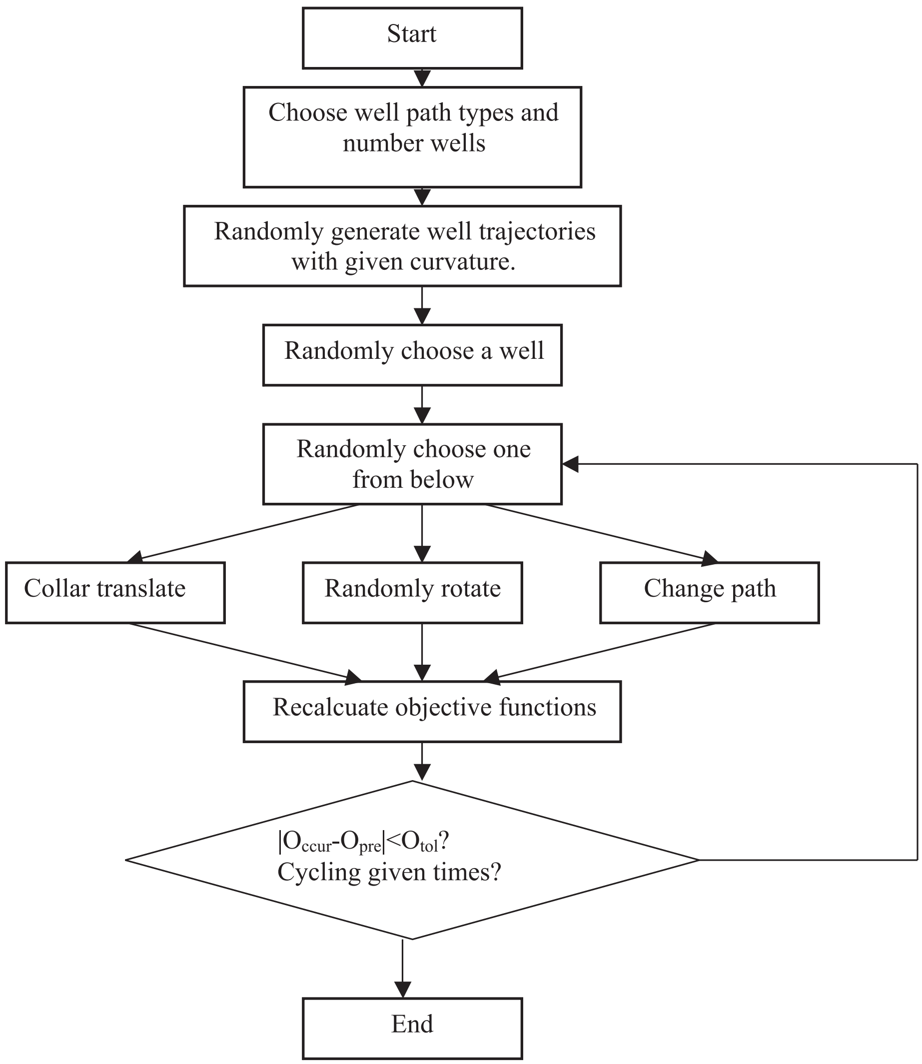

Figure 7: Flow chart for optimization algorithm