Comments to "3-D seismic survey design as an optimization problem" by Liner et al., TLE, September 1999

Whatever method is selected to arrive at a 3-D survey design, there will always be a number of alternative geometries from which a final choice has to be made. All of them may be geophysically acceptable and also cost-effective, but then the question is: "Which one is best?" Liner et al. (TLE, September 1999) propose an interesting solution to this problem, which involves minimizing a cost function dependent on deviations from the target parameters. In the following I discuss some beauty failures of the paper and I propose some modifications to the optimization process.

The paper's Figure 1 shows vertical receiver lines and horizontal source lines. At each intersection point of the acquisition lines a source and a receiver station coincide. From 2-D acquisition it is known (Hobson, 1985, First Break; Knapp, 1985, TLE), that source and receiver station should not coincide, because this leads to the acquisition of reciprocity traces (pairs of traces with shot and receiver position interchanged), which probe the subsurface in exactly the same way. The same applies to 3-D. Relatively, there will be fewer reciprocity traces in 3-D than in 2-D; yet, it is a waste of resources to acquire such traces. Fortunately, the optimization solutions in the paper always have non-coinciding source and receiver positions.

Assumptions and basic equations. We assume the data will be acquired using the shot-centered template method (Figure 1).

This acquisition method is common and very flexible (swath shooting is a special case).

The shooting template is described by two orthogonal coordinates, (x, y), and six parameters:

1) s_x = shot interval in x-direction
2) s_y = shot interval in y-direction
3) r_x = receiver interval in x-direction
4) r_y = receiver interval in y-direction
5) n_x = number of live receivers in x-direction
6) n_y = number of live receivers in y-direction

Using generic x and y avoids confusion related to various definitions of the terms *in-line* and *cross-line*. Table 1 gives a full list of symbols.

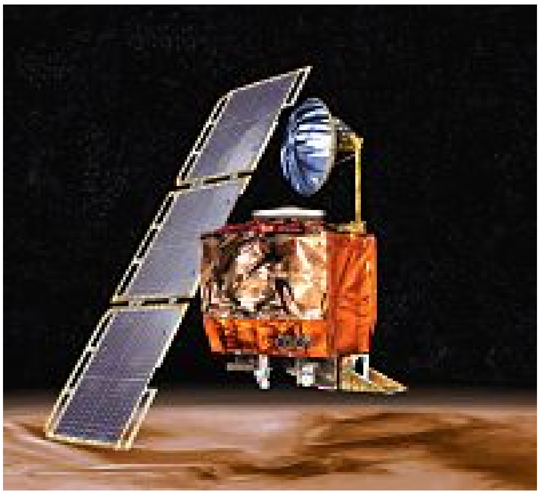
Given a set of six design parameters, we can simulate all the necessary quantities

$$
\begin{aligned}
b_x &= 0.5\, min(s_x, r_x)\\
b_y &= 0.5\, min(s_y, r_y)\\
f_x &= (0.5\, n_x\, r_x)/s_x\\
f_y &= 0.5\, n_y\\
f_{3d} &= f_x f_y\\
n &= n_x\, n_y\\
t_x &= (n_x - 1)r_x\\
t_y &= (n_y - 1)r_y\\
a_r &= t_x/t_y\\
x_{max} &= 0.5\sqrt{t_x^2 + t_y^2}\\
x_{min} &= numerical
\end{aligned}
$$

Effectively, this array of equations says that given $(s_x, s_y, r_x, r_y, n_x, n_y)$, we can simulate a unique set of outputs $(f_{3d}, b_x, b_y, x_{min}, x_{max}, n)$.

The formulas for f_x and f_y given in the paper (see copy of text) are asymmetric. This is an improvement over the formulas given in the Expanded Abstract of the 1998 SEG Conference paper. However, the formulas imply that the receiver lines run parallel to the x-axis and the source lines parallel to the y-axis. Figure 1, which is meant to illustrate the nomenclature, is confusing because here the source and receiver lines run perpendicular to the implied directions. (The reason that the formulas have to be asymmetric lies in the selection of the six parameters (s_x, s_y, r_x, r_y, n_x, n_y) with which to describe the template, n_x being the number of receivers in x, i.e., the number of receivers in a receiver line listening to a range of shots in a shotline, and n_y being the number of receivers in y, i.e., the number of receiver lines. Defining n_y analogous to n_x, i.e., as the number of shots in a shotline shooting into a range of receivers in a receiver line, then f_y can be written as $f_y = 0.5\ n_y\ s_y\ /\ r_y$, and symmetry is restored. This formula for f_y is the same as in the Expanded Abstract, but now with the correct definition of n_y.)

Normally, we sample in order to approximate an underlying continuous function. But what is the length of a line segment represented by N samples at distance d from each other? The correct answer is Nd, and the authors use this answer in their formula for f_x. Indeed, in-line fold equals spread length / (2 x shotpoint interval), and spread length = number of receivers x receiver interval. However, to measure the width (= spread length) and height of the template, the authors use $(N\text{-}1)\ d$. This leads to funny arithmetic: if the number of samples is doubled (keeping d the same), the length is not doubled. This mistake is made by 9 out of 10 authors who use sampling in their research.



Because they use incorrect formulas for width and height of the template, the authors find incorrect values for the maximum offset x_{max}, even though the formula for x_{max} is correct. Note that template width = 2 x maximum in-line offset and template height = 2 x maximum cross-line offset. In this way the number one solution of the discussed design problem has x_{max} = 5700 ft (a bit dangerous to use an archaic unit system as the Mars Climate Orbiter recently demonstrated), whereas the authors' program finds 5291.45 ft.

The formulation of the optimization problem might be modified somewhat to ensure even better solutions. In the first place, it would be advisable to include also a measure for the ratio between shotline interval and receiver line interval, the optimal ratio being 1.0. For ratios smaller than 0.5 or larger than 2.0, the shallow coverage will be very irregular. For instance, in the authors' number one solution, shotline interval is twice as large as receiver line interval. This leads to higher fold along the shot lines than along the receiver lines. A further refinement might be the optimization for different target levels, each level having its own requirements.