Introduction

The Value of Information (VOI) relates to making better decisions under uncertainty. It is an old concept in the petroleum industry. Researchers worked on it a couple of decades ago (Grayson 1962), but then it seemed to calm down. Recently, it has gained more interest in the industry (Bratvold 2007). The VOI is useful in several petroleum applications where one considers purchasing more data before making a decision. The data comes with a price, and one might ask if it is really worth it, or when it is optimal to perform the additional data acquisition? We consider this situation by using two constructed examples that have interesting similarities.

Consider for instance the placement of a new well in a petroleum reservoir, we can drill horizontal or vertical wells, but when we are close to the reservoir or a high pressure zone we usually drill carefully to avoid blow-out. The well position is usually determined by magnetic measurements, but before entering a particular zone, we could purchase a monitoring survey in the form of gyroscopic measurements (Torkildsen et al. 2008) to increase our accuracy in the position estimate. When do we get the highest value of this data? The VOI can be used to find the optimal time of performing a gyro survey in different reservoir situations.

Another example is detecting un-drained pockets of oil or gas in a reservoir. In this case we have a priori information about the potentially remaining pockets of oil from baseline seismic, geological understanding and reservoir simulators. We consider drilling new wells in these un-drained zones, but we can make better decisions by collecting a seismic monitoring survey (Landrø et al. 1999), or a repeated electromagnetic survey. However, such data are expensive, and unless they help us change our drilling decisions, they are not worth the cost. The VOI is used for predicting expected potential revenues and values, before purchasing data. Based on this we can find the optimal time of acquiring a seismic monitoring survey.

Theory: Calculating the value of information

Assume a distinction of interest with associated revenues. This could be the saturation distribution in the reservoir. We want to maximize profits, and thus produce the reservoir if revenues are higher than the cost of drilling and development. In other situations we want to minimize the loss. For instance, we would drill with casing if the risk of blow-out is too high. In most decision making contexts we can purchase more data to make better informed decisions. The VOI is defined as the maximum cost that we should pay for new information. If the price of data is smaller than the VOI, the data is not worth its price (Bratvold et al. 2007). The VOI is the Expected value WITH additional information minus the Expected value WITHOUT additional information. The former is sometimes called posterior value while the latter is the prior value.

The above mentioned definition should be adapted to the application of interest. For example, in the situation with casing / not casing we have a cost C_{wc} of drilling with casing and cost C_{woc} of drilling without casing. To save money we prefer to drill without casing, unless we are close to a high pressure zone / reservoir. Denote the distance to target by Z, and the drilling leg value L. A blow-out occurs if the distance to target is less than the next leg, and the cost is C_{bo}, which is much more than the other costs. Here, we should use the best solution at all times to minimize loss. Possibly, the gyro measurement can help us make better decisions about casing/not casing. We define

$$\text{Prior value} = -\min(\mathrm{C_{wc}}, \mathrm{C_{woc}} + \mathrm{C_{bo}} \cdot \Pr(\mathrm{Z<L}))$$

$$\text{Posterior value} = -\int \min(\mathrm{C_{wc}}, \mathrm{C_{woc}} + \mathrm{C_{bo}} \cdot \Pr(\mathrm{Z<L|Y}))\pi(\mathrm{Y})dY \;.$$

Here, Y is the new gyroscopic measurement with probability density function $\pi(\mathrm{Y})$.

The other example is for deciding on drilling / not drilling new wells based on AVO seismic and/or CSEM resistivity data. In this situation we want to maximize the cost, and we drill the well only if the expected oil revenues are larger than the cost of drilling. The VOI concept can be used to check if a seismic monitoring survey is worthwhile pursuing, before making the drilling decision. The value of unexplored oil is directly relate to oil saturation, $(1-s)$, porosity, ϕ, and an scaling term, R, that involves factors such as oil price, recovery factor, net-to-gross and thickness (Eidsvik et al. 2008). We have a cost C of drilling a new well to drain the un-drained pocket. In this case we are interested in maximizing profit, and thus define the VOI as follows:

$$VOI = \int \max\left(R \cdot E\left[\phi(1-s)\,|Y\right]-C,0\right)\pi(Y)\,dY - \max\left(R \cdot E\left[\phi(1-s)\right]-C,0\right).$$

Where Y is new seismic AVO data with probability density function $\pi(\mathrm{Y})$. If the VOI is larger than the price of a monitoring survey, we buy and use it, with high success probability, on average.

Numerical example 1: Decision on Casing / Not Casing using gyroscopic monitoring data

We are looking for an optimal point (or optimal time in the dynamic case when we simultaneously drill and evaluate the VOI) for starting to drill with casing. The gyro data might help us make the decision. Intuitively, for positions which are far away from reservoir, the VOI is low because it is not dangerous to drill without casing. When we get closer to the reservoir, the VOI increases because the gyroscopic measurement can actually help us change the decision about casing. When we are very close to the reservoir, we use casing in any event and the gyro data is not required. Thus, the VOI becomes small again. The parameters used in our calculations are as follows ($C_{wc} = \$1$ million, $C_{woc} = \$100$ thousands, $L = 30$ m and $C_{bo} = \$10$ millions):

Figure 1 shows the VOI (second axis) as a function of the prior distance to target (first axis). The VOI is small for very small distances from target, since we would mount casing in any event. No additional data is required. Similarly, for very large distances, the VOI is small since we would avoid casing with or without gyro data. For intermediate distances the gyroscopic measurement gives a high VOI since it could change our decision about casing / not casing.

In Figure 1 (left) we assume a prior standard deviation of 10 m for the drill-bit depth, while Figure 1 (right) is constructed with a prior standard deviation of 25 m. In each display we show the VOI for 4 different levels of gyro measurement uncertainty: 3m, 5m, 7m and 10 m. For a small prior uncertainty (left) the highest VOI is around 45m from the target, while the VOI is at its largest for 65 m in Figure 1 (right). Naturally, this means that we can postpone the gyroscopic measurement longer when the prior uncertainty is small. The value of a monitoring gyro survey is larger closer to the target.

The VOI gets as large as \$0.7mill for high prior uncertainty (right), while its highest value is just under \$0.7 mill for smaller prior uncertainty (left). Obviously, the four curves in each display shows that the VOI increases with gyro accuracy. This increase is larger for small prior uncertainty in Figure 1 (left) where we have VOI=\$0.45mill for 10m gyro uncertainty and VOI=\$0.7mill for 3m gyro uncertainty. The corresponding increase in Figure 1 (right) is \$0.66mill to \$0.77mill. The increased gyro accuracy becomes more valuable when the prior accuracy is already quite high. Next, assume the gyro measurement costs \$0.7 mill. Then, it would be worth the cost only for the situation displayed in Figure 1 (right), for distances near 65 m from target, and only for quite high level of gyro accuracy. Otherwise the VOI < \$0.7 mill and the gyro monitoring survey is not worth its cost.

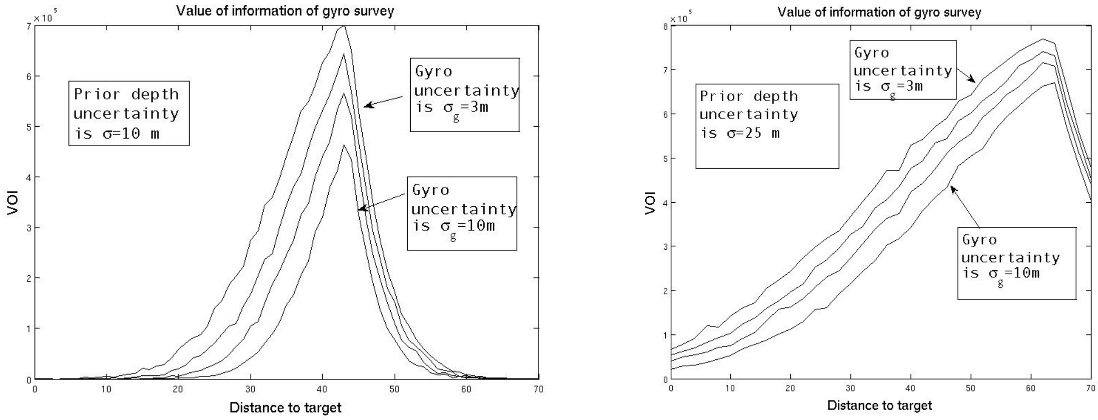

Figure 1 *VOI with respect to distance to target for different values of prior and likelihood uncertainties.*

Numerical example 2: Decision on drilling / not drilling using seismic monitoring data

Finding and drilling unexplored pockets of oil and gas is very important in petroleum industry. It directly relates to money, it is important for both oil companies and the national economy (Landrø et al. 1999). If an oil company drills a dry well, they lose much money and reputation. If some undrilled oil/gas pockets exist, the government cannot use all potential revenues from that field. Good decisions about drilling or not drilling are very important here.

Figure 2 shows the saturation profile in a synthetic reservoir study. In practice this image can be constructed from ensembles of reservoir models. In our setting this would give prior saturation and porosity values. Figure 2 shows a synthetic case where we have produced oil from the upper right corner, while water is injected in the lower left corner. One might suspect an un-drained pocket of oil near the central domain. In such a situation it could be valuable to collect more data (seismic AVO or CSEM resistivity data) to make better decisions about placing additional wells to drain the segments better and get a higher production rate from the reservoir. Our prior model and parameters are copied from Eidsvik et al. 2008. We consider $C = \$2$ mill,and $R = \$15$ mill $0.1 < s < 0.9$, $0.15 < \phi < 0.4$. The rock physics likelihood model is based on a sand-shale mixture model, see Eidsvik et al. 2008.

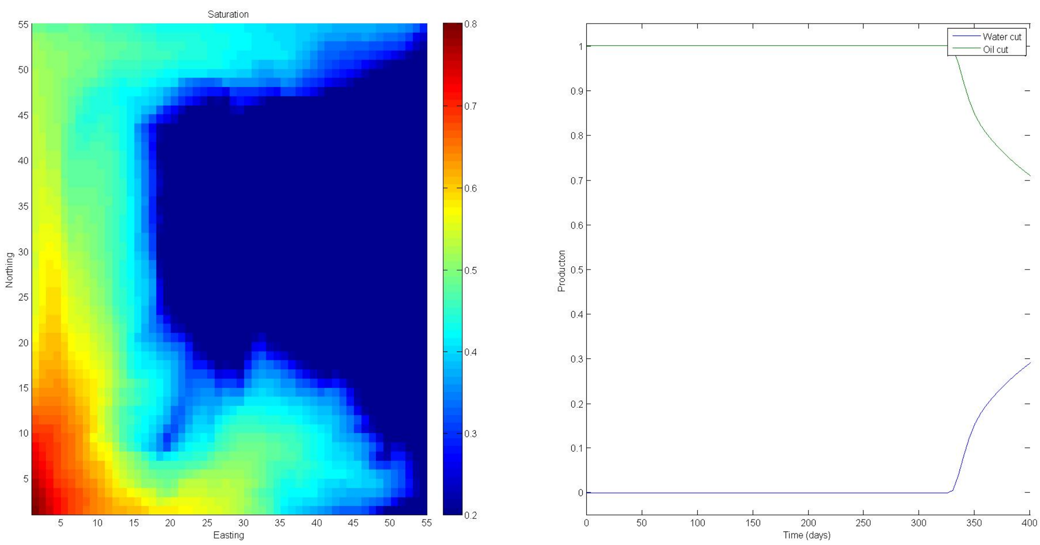

Figure 2 *Saturation profile in a synthetic reservoir study (left) we have produced oil from the upper right corner, while water injected in the lower left corner (right) production rates.*

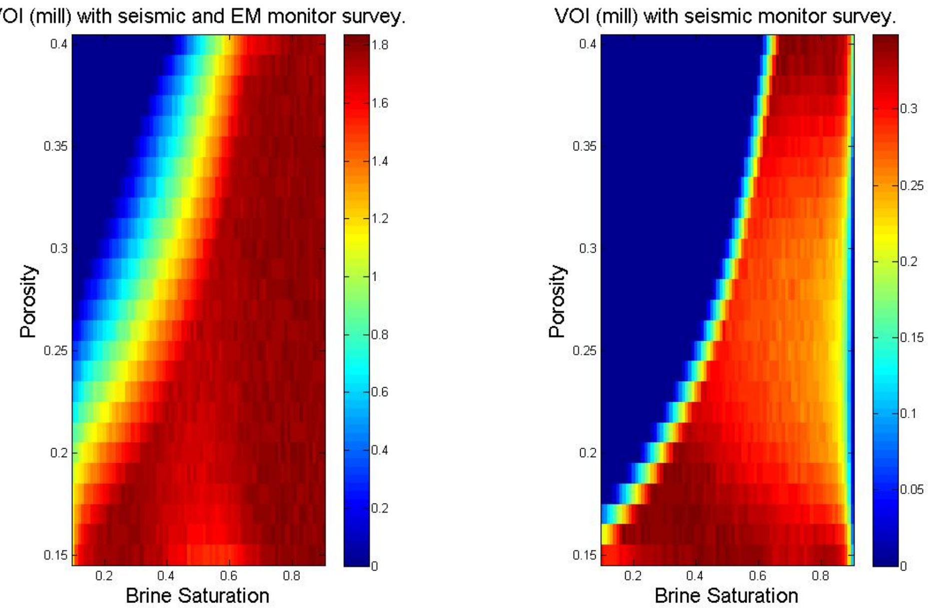

***Figure** 3 VOI as a function of brine saturation and porosity. Left) with seismic AVO and EM, Right) With only seismic AVO data.*

Figure 3 shows the VOI as a function of brine saturation (first axis) and porosity (second axis). In Figure 3 (left) we consider purchasing both seismic and CSEM monitor surveys, while only seismic monitor data is considered in Figure 3 (right). Naturally, the VOI gets higher (1.8 mill) with CSEM data than without CSEM data (0.35 mill), since we have more data, and make better, informed decisions. CSEM data is quite sensitive to saturation, and will reduce the uncertainty much, if the resolution is high enough. Interestingly, the highest VOI for seismic AVO occurs for low and high porosity, and not intermediate values. The highest VOI occurs for intermediate prior saturations. For high porosity neither CSEM nor seismic data are worth the cost if the prior brine saturation is too small. These interpretations can be interpreted from the rock physics relations used in this study.

Conclusions

Value of information directly relates to making better decisions under uncertainty. We presented two applications of it in the petroleum industry. The examples are static, and we are looking into ways to extend it to dynamic cases (i.e. simultaneously drilling or monitoring flow, and valuing of the information).

References

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