

Geothermal Probability of Success and Conceptual Well Design

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Keywords: probability of success, expected value, decisions

ABSTRACT

Good decisions drive cost effective geothermal projects. Effective development decisions in uncertain conditions rely on forecasting the performance of the proposed facility. The uncertainty and high cost of drilling projects makes forecasting performance of a proposed well a key geothermal expertise. Probability of success (POS) for a well can succinctly express a forecast when based on a clear definition of success.

Extensive work on processes associated with forecasting international political events have demonstrated a “style of thinking” that can markedly improve successful forecasts in uncertain settings (Tetlock and Garner, 2015). Team thinking processes developed at Unocal to make drilling decisions had important similarities to the styles later recommended from these international studies. The Unocal decision process on drilling projects helped reduce drilling costs to around 50% of industry averages. This large impact on costs should encourage work on decision processes in geothermal development in order to attempt similar cost improvements.

Beyond a decision about whether and where to drill, estimates of the POS can be used to compare relative expected values of well designs. Although expected value comparisons are simplistic, they provide a monetary value context that supports good team-based well design decisions. Expected value examples for two well design decisions are shown including a decision on whether to drill a slim hole or a standard well and whether to drill a directional well or a vertical well. Results suggest that expected slim hole value is lower than well value except in low quality targets. This helps frame other issues such as strategic values, access costs, and drilling risks. In the case of directional wells, calculations suggest that a deviated well should be planned when the improvement of the well POS is .05 or greater.

1. INTRODUCTION

Unocal, including its geothermal division, had a remarkable record on well costs. In spite of using the same drilling technology and tools as other operators, Unocal oil and gas and geothermal well costs were typically around 50% of competitors (Unocal Corporation, 1999) through the period from about 1995 through 2010. O’Donnell (2002) showed examples of well depth – day charts that show consistently faster average drilling rates compared to competitors for offshore wells (Figure 1). Geothermal wells at Awibengkok field, Indonesia were also drilled much faster and cheaper than wells drilled in other fields in West Java, even when the other operators used similar well designs, equipment, drilling processes, and some of the same contractors as Unocal. The Unocal learning process reduced the average well drilling days at Awibengkok from 53 to about 20 days over 15 years (Soeparjadi et al, 1998 and Prihutomo and Arianto, 2010). Based on experience in geothermal work Unocal drilling performance was strongly facilitated by a team process including forecasts of decision impacts and designs, detailed review of data, and multiple critical opinions in advance and in review in an empowered setting.

Meanwhile a study of forecasting of world political events defined a “style of thinking” that results in improved forecasts (Telock and Garner, 2015). This style has similarities to the Unocal team thinking style, although the later studies reveal more detail and have a higher level of insight compared to the Unocal day to day processes and reports.

2. SUPERFORECASTERS

The international study of forecasting involved a tournament of forecasts of world political events by individuals and teams with participation of about 20,000 people (Tetlock and Garner, 2015). Forecasts were checked against actual results over 5 years. During the study it became clear that certain groups were consistently much better forecasters than others. Mellers et al (2015) showed that the best teams consistently produced forecasts that were roughly 50% more accurate (e.g. Figure 2) and showed strong learning improvements. These teams are referred to as superforecasters. A lot of analysis went into showing that this was not pure luck and to identify what helped create the differences in performance.

One study of the contrasts between the best forecasters and teams and others revealed a style of thinking that was consistent with better performance (Tetlock and Garner, 2015). People and teams that achieved more frequent successful forecasts were:

1. Self-critical
2. Detail oriented
3. Open minded

4. Accountable

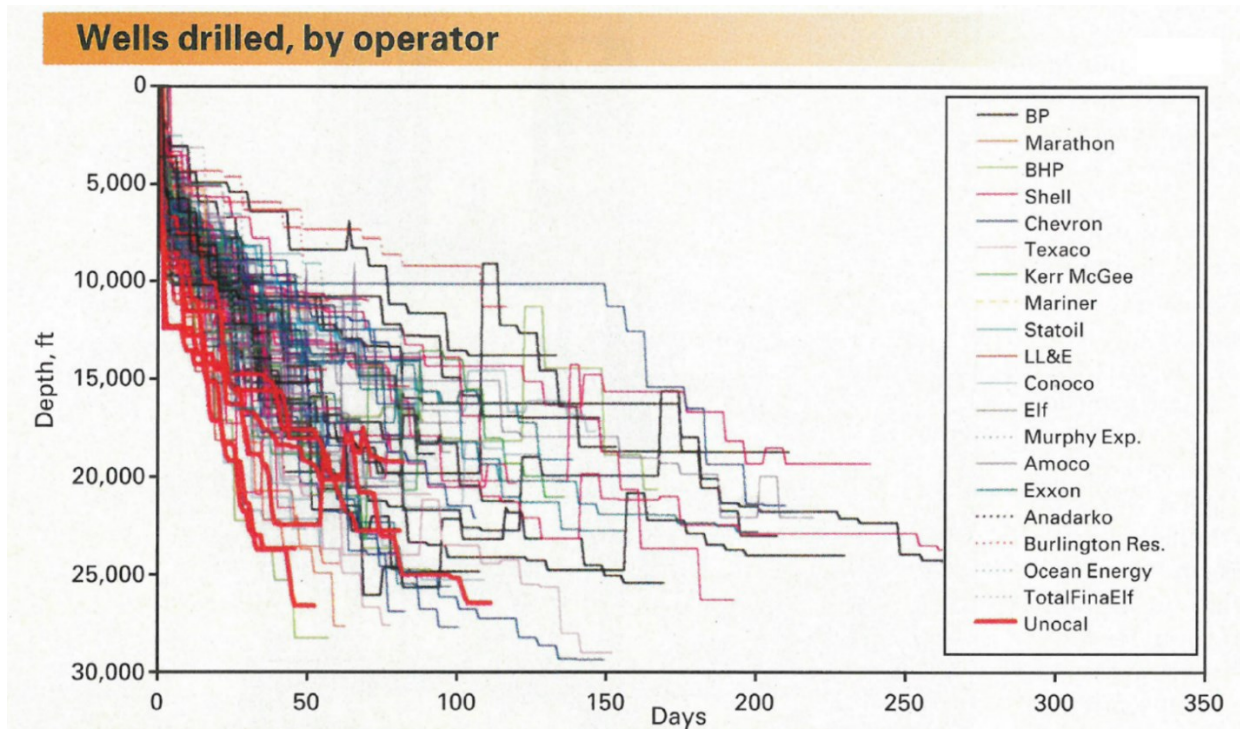


Figure 1 Well Depth vs Days Chart for Wells Drilled in the Gulf of Mexico Between 1995 and 2002 - Note the consistently faster drilling of the Unocal wells (shown in red).

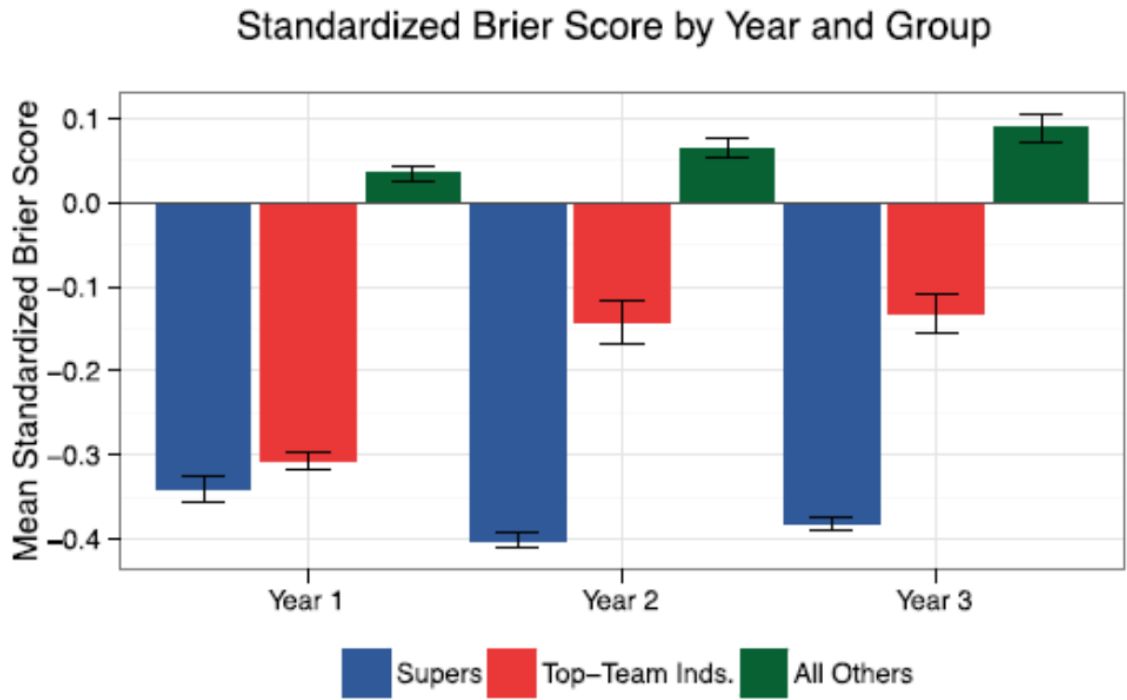


Figure 2 Standardized Brier Scores of Groups and Individuals – Mean standardized Brier Score refers to the difference between the mean of all scores and Brier Score for one team or individual. The Brier Score = $(\sum(POS_i - o_i)^2)/N$. N event questions are defined to have an outcome (o_i) represented by either 1 if it happens or 0 if it does not happen. Differences in a mean Brier

Score of 0.3 would reflect typical forecast accuracies that are greater by around 50%. “Supers” refers to the best forecasters. “Top-Team” refers to the second tier best individuals.

Successful forecasters were also more likely to believe that they could acquire skills to become better forecasters, i.e., that it wasn't just talent or intelligence or better information. Part of being accountable involved committing to a numerical probability for an event. Review showed that precision in estimating the probability of an event correlated to the score of the forecast (Tetlock and Garner, 2015).

The comparison of the Unocal decision process to descriptions of superforecaster behavior is qualitative but based on personal experience from 1996 to 2004. The Unocal drilling team process involved open-minded and critical interaction, testing of ideas and equipment, and detailed engineering before and after drilling events to forecast and review results. The team process was supported by a trustful environment among team members that allowed challenging communications and full empowerment by the company. Part of the drilling decision work included geothermal well targeting using multiple targeting and conceptual models.

Multiple Conceptual Models

One approach to a superforecaster style of thinking for exploration and development well planning uses multiple conceptual models. It is not the models themselves that make the difference but rather the thinking process that helps fully explore and visualize possible outcomes with multiple data sets and team members. The development of multiple specific and detailed models helps perform all four of the characteristics of superforecaster thinking cited above. One of the advantages of using multiple models is that it frees up the thinking from “what is the right model?” to become “what could the model be?” This is practical since in uncertain geothermal conditions, especially during exploration, a single model is very likely to be wrong.

Although a range of models is interesting and educational, no model is useful unless it drives a decision. Consequently the models have to be linked to actions. The clearest link is to define the POS of a particular project, such as drilling a well, based on the range of models. In some cases POS can be used to estimate the expected value of the result, which provides a monetary context that can be useful in decision making as described below.

Another link connecting multiple models to decisions is communication with management that may not be familiar with the decision process. Communicating multiple models can result in management thinking that the team is saying “it could be this and it could be that” and result in managers thinking “if they don't know then I will have to decide”. Consequently it is important for the technical team to lead the communication with a favored model (not necessarily the middle option), express the breadth of thinking with other models or aspects of models, and then ideally to define a decision or drilling program that is robust to the range of models.

Estimating POS

Although detailed methods of estimating POS for a geothermal well are not a subject of this report, generally the POS should be defined by a multi-disciplinary team that reviews detailed data and how the data support each of multiple possible outcomes. Appropriate team characteristics and behaviors in this endeavor should be informed by studies of successful forecasting. The impact of learning on well success rates (e.g. Sanyal and Morrow, 2012) clearly shows the advantage of using previous drilling results to help improve well POS. The population of actual success rates of previous wells in the same or similar fields can help constrain the probabilities. The International Finance Corp. (2013) demonstrated that well productivity populations show lognormal distributions, providing further constraint on the probability distribution.

Expected Value Well Design Comparisons

Expected value (EV) is simply the product of the value of a project times the likelihood that the value will occur, i.e. $EV = \$ \times POS$. So for example a geothermal well might be simplistically evaluated by combining the expected values and expected costs of drilling:

$$EV = \text{Well Value} \times POS - \text{Well Cost}$$

This equation is simplified by the assumption that once the decision to drill is made the well cost has a probability of 1. Well values can be based on the net present value of prospective steam sales but can also include information value. This equation represents the balance of the success and failure cases in monetary terms. If the expected value result is negative then the project should not proceed unless there are other important values not included in the calculation.

In the case of a slim hole the expected value calculation is complicated by the fact that most slim holes are never connected to a plant (e.g., the cost of hooking up the well may be greater than the value of steam sales or injection due to low flow capacity in a narrow wellbore) such that the hole has little direct financial value.

In the following simple example the information value of the slim hole is based on the financial value of a follow-up standard diameter well into the same target.

$$EV = (\text{Standard well value} - \text{Standard well cost}) \times POS - \text{Slim hole cost.}$$

In this equation the information value of the slim hole is embodied in an assumption that a standard well will only be drilled and is assumed to be successful (with POS = 1) if the slim hole is already successful. In this case the slim hole is essentially a pilot hole. The POS in this equation is the probability of success of the slim hole.

This simplistic formulation of the expected value of a slim hole is used to represent the range of possible information values and should inspire a discussion about what should be included as value and how much is it worth. This discussion may even be the most important result of the expected value formulation. Beyond the value of follow-up well production, further direct monetary value of slim hole information is limited or delayed. For example, geothermal field development is never triggered by a successful slim hole, one or more standard wells are always required before commitment, often after significant delay and much larger drilling investments. Regarding reservoir information, in most prospects the occurrence and estimated temperature of a reservoir although uncertain are already partly evident from springs, fumaroles, and alteration indicators before drilling such that hole information might only refine previous data. Of course the additional slim hole information is useful and can reduce risk but at a significant cost. In a blind prospect slim hole data has more value and in some cases has provided the only hydrothermal data available. There are other information values for slim holes like later uses of the hole for monitoring or adjustment of targets for development wells. Geophysical monitoring performed later might be a useful value comparison. For the example calculations below all these values are subsumed within the 100% POS for the follow-up well value.

To show how the expected values based on the above equations vary with POS, calculations were performed with reasonable costs and values to produce Figure 3. Cost numbers used to generate the plot included a well cost of \$5M and a slim hole cost of \$2.5M. Drilling costs assumed a slim hole completed with cemented casing of 5” or less and a full size well completed with cemented casing of 9 5/8”. The standard well cost is consistent with estimates from Capuano (2010), Lukawski et al (2016), and Tester et al (2015). The standard well value was based on a simple net present value calculation for a reasonable steam flow schedule and power price that resulted in a value of about \$10M.

Under these assumptions and equations the information value of a slim hole is accounted as \$5M, which seems high and enough to fully represent the possible information values. These estimates result in the same cost/value ratio for a slim hole and a standard well such that neither project is preferred by the ratio. This provides qualitative justification that the slim hole information value is not discounted for the calculation.

As shown in Figure 3 (and consistent with expectations) the standard well is more valuable at high POS and the slim hole is relatively valuable at low POS. In other words why drill a slim hole if you are likely to be successful with a standard well? Alternatively if the prospect is risky maybe you shouldn’t start with a full-sized well (or maybe drill at all.)

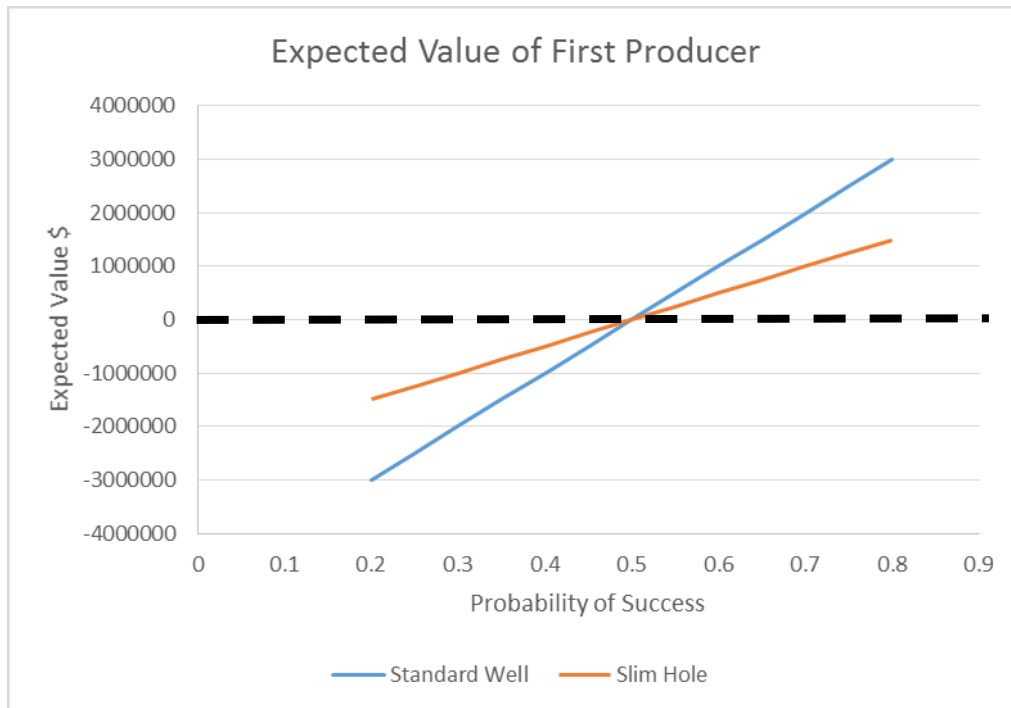


Figure 3 Expected Value Comparison of a Standard Well Versus a Slim Hole and Follow-Up Producer. For these assumed values the dashed line marks the division between positive and negative expected value.

In Figure 3 the two equations show a cross-over at a medium POS. We can equate the two formulas for expected value above to investigate how this cross-over varies with different costs and likelihoods. The equation reduces to:

$$\text{Slim hole cost/Standard well cost} = 1 - \text{POS}$$

Note that in this equation the values cancel out entirely and the drilling costs are expressed only as a ratio. This simplifies the comparison and avoids the specific cost and value assumptions. A plot of the resultant equation is shown in Figure 4.

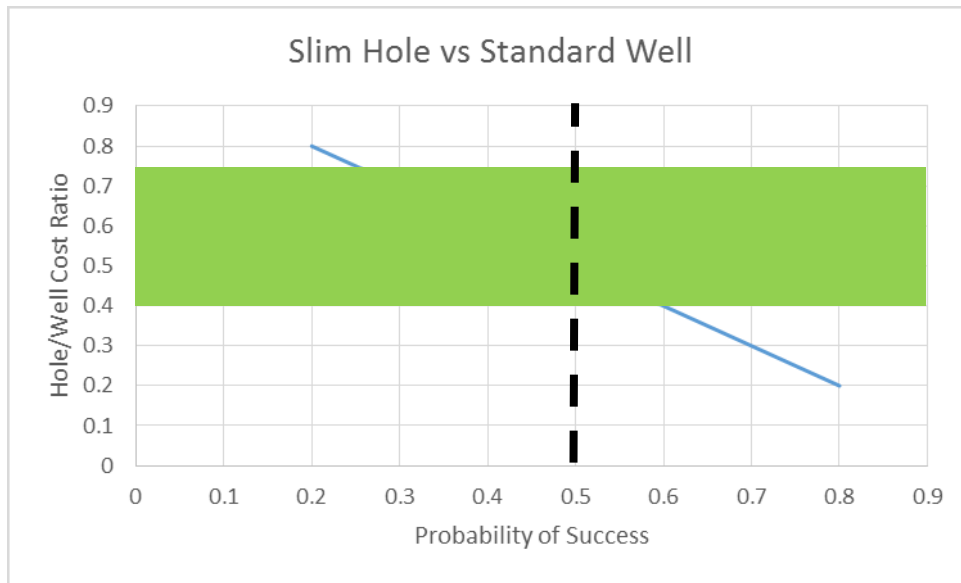


Figure 4 Equivalent Expected Values for a Slim Hole and a Standard Well. Areas above the blue line result in higher expected value for a standard well. The green band shows the range of likely cost ratios. The dashed line separates regions where the drilling is expected to be successful or to fail. The plot suggests drilling a slim hole only if it can be drilled very cheaply or if overall project values support drilling holes that are expected to fail (i.e. POS < 0.5).

At this point it is useful to review the likely ratio in hole/well costs. Finger and Jacobson (2016) described three geothermal well pairs that help compare actual slim hole and larger diameter rotary-drilled well costs in the same prospects to comparable depths. The cost per meter ratios in these comparisons were 0.4, 0.6, and 0.72. Oil and gas comparisons including many more wells suggest ratios of 0.4 to .75 (e.g. Shackleton, 1997; Zhu and Carroll, 1994, and Flatt, 1959). Nielson and Garg (2016) indicate that they can achieve much lower slim hole costs.

This display of relative values does not provide a decision for specific well plans. Clearly if the access to the slim hole location requires \$1 million of helicopter cost while a full well would require a \$5 million road or rig mobilizations have strongly different costs then the calculation and the decision could also be different. Or if you had to either drill a well or lose the concession then rapid access with a slim hole rig might provide important strategic value. On the other hand a slim hole rig has limited depth, directional, and well control capability such that it may not reach the target and has a higher well control risk. So the full design decision is more complicated and it may be useful to apply more values and likelihoods in an expected value calculation. In the end the decision can be informed by expected value calculations but will be based on judgement across the full range of issues. The expected value calculation can balance some of the major issues in simple bottom line terms.

Another useful example reviews the expected values of vertical and directional wells. Similar to the above examples expected value equations for the two proposed wells can be expressed respectively as:

$$EV = \text{well value} \times \text{POS}_v - \text{well cost}$$

$$EV = \text{well value} \times \text{POS}_d - (\text{well cost} + \text{directional cost})$$

Where the two POS values refer to vertical (POS_v) and directional (POS_d) well targets. Equation of these two formulae reduces to:

$$\text{POS}_d - \text{POS}_v = \text{directional cost/well value}$$

This describes a relationship for when the two proposed wells have equal expected value.

If we assume that:

$$\text{well value} > \text{well cost}$$

then we can convert this equation to:

POS_d - POS_v < directional cost/well cost

In other words in order for the directional well to have higher expected value, the POS of the directional target only has to exceed the POS of a vertical well target by less than the ratio of the directional cost to the well cost. Studies on geothermal well costs (Lukawski et al, 2016 and Capuano, 2010) suggest that directional drilling represents 3% of the total well cost. Assuming a more aggressive than usual directional program to reach a specific target can justify raising the directional cost estimate to 5%. So a decision to directionally drill a well would be favored by a team evaluation that the relative POS of the targets are different by at least 0.05. If well value was twice the well cost as suggested in the first example then the required difference is only 0.025. So if the well site location is restricted by terrain and the best target is clearly below nearby difficult terrain, then a directional well should have greater value. In contrast the model of oriented fractures in the reservoir that controls wells success rates has not been shown to be generally valid and might not justify the directional cost. Well interference for development wells on the other hand probably can justify the directional cost depending on reservoir phase and permeability. However this decision but might be better studied with a different formulation of expected value.

CONCLUSIONS

Project costs are strongly dependent on decision processes in costly uncertain projects such as drilling of geothermal wells. Effective team decision processes have been accompanied by excellent drilling cost and well results in both oil and gas and geothermal projects. Decision processes have been extensively studied in other settings as well, providing powerful tools to improve forecasts of the possible results of decisions. These studies recommend development of certain styles of thinking in teams.

Well drilling and design decisions can be supported by team forecasts of the probability of success. Implications of these forecasts can be expressed in monetary terms using formulations of expected value. While the decisions are often more complicated than can be usefully expressed in an expected value calculation, the expression of the forecast in monetary terms can balance values for some important issues as well as provide a persuasive impact on decision makers and executive management.

The simple case examples in this report are individually useful in exploring common conceptual well design decisions, however the key message is that decision processes are important performance skills and should be a focus of study in our effort to improve the economic and environmental values of geothermal projects. A few decision processes have been described here but teams should consider others.

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