Exploration Chance of Success Predictions – Statistical Concepts and Realities

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SUMMARY

There is much confusion in the conceptualisation and application of Chance of Success (COS) Predictions in oil and gas exploration. Although the basic statistical underpinnings of COS predictions are not mathematically complicated, in practice, there appear to be significant difficulties. The consequences of this in many cases include misplaced expectations and hence morale problems from results of exploration which fall outside expectations. In reality, commercial exploration success rates worldwide range from 30-40%. So, there is more pain than not in our industry with the unfolding of expectations. As a result of this, companies have many times reacted in a knee jerk fashion to 'correct' their course which sometimes results in restructuring exploration teams and also changing the course of exploration. Much of the misunderstandings appear to arise from the fact that most small companies are involved in limited trials campaigns where budgets allow the drilling of only a handful of wells over 1-5 years. Realistic COS' can only be based on expectations related to drilling a statistically significant large number of wells. In this paper the vagaries of the actual unfolding of exploration results are simulated using MS Excel software's Random Number Generator function. Despite the intrinsic difficulty of not being able to guarantee any specific success, it will be shown how companies can choose the COS range they should be involved in to enable sustainable growth over the longer term.

All the concepts and thoughts presented here are those of the author's and do not necessarily represent the author's employer Cue Energy's views on this matter.

Key words: Exploration, prediction, statistics, chance, failure, success, binomial, random

INTRODUCTION

The focus of most Exploration teams is in the analysis of the Geological aspects of an Exploration opportunity. The estimation of the pre drill prospect COS comes at the end of this process. Most Geoscientists who participate in the COS estimation have at least some understanding of probabilities but it is not usual for most Geoscientists to think too deeply about the underlying statistical principles assumed in the process. This affects the manner in which a COS is conceptualised and conveyed to other stakeholders including managers and shareholders. More often than not, even the proper conveying of what a COS stands for pre drill does not appear to prevent the ongoing element of surprise when a well comes in dry. This is despite the fact that on the average, globally, 60-70% of all exploration wells are not commercial. This outcome is in spite of the fact that most companies spend a great deal of time and effort using the best in technology and manpower prior to deciding to drill prospects.

The purpose of this paper is to reveal the actual statistical nature of exploration drilling. That each exploration test is part of a random trial. The very random nature of exploration trials makes it impossible to predict the outcomes of wells exactly. But more important is the fact that most companies do not drill statistically sufficient number of wells over a corporate horizon of 1-5 years. At the heart of much of the confusion relating to interpreting post drill failure/ success, is the fact that most companies are involved in limited trials campaigns. Limited trials are at odds with predicted COS which are long run expectations. It is not unlike expecting the result of a coin toss to come up with heads or tails after two throws but in reality finding out that this may not occur as expected and that the 50% COS expected is true only as a longer term average expectation after a statistically sufficient number of throws.

Given the complex nature of the subject, it is nearly impossible to answer all questions that can occur in one's mind about this subject. However, it is hoped that some if not most of the questions that arise are fully or partly answered with this paper. Typical of the questions asked by intelligent practitioners, if not in jest, at least to convey their sense of non-understanding are: 1) What is a COS number, really? 2) The result of a well is either a one or a zero. How is COS relevant? 3) The COS is a Subjective number. 4) The COS is an Objective number. 5) What has drilling wells got to do with dice throws and random numbers/ trials? 6) If the COS is 20%, then one out of 5 wells in a campaign should be successful, right? 7) If your COS is 20%, just drill the one successful well and avoid drilling the other 4!! 8) How do you evaluate proficiency of COS predictions by a team? What is a good exploration team performance? 9) When do we know that our COS' are off the mark – how many wells before we ask questions? 10) Only good exploration teams make discoveries – right? 11) Good exploration teams do not drill dry wells - right? 12 How does all of this help companies make money?

It is hoped that in the material that is provided below, more light will be shed on some if not all the questions above.

PREVIOUS WORK

Much has been written on the subject of Exploration Risk in the past and some of the key works are listed in the References below. However, it has been found that there is not much in the literature that goes to the very basics of the Statistics underlying the playing out of real life exploration campaigns. In the literature, it is assumed that everyone understands what a Statistical Expectation is. The fact that in the drilling of wells, being a random trials experiment, the real blow by blow playing out of success or failures has huge impacts on the lives of especially smaller, limited budget companies and their staff members. As the Statistical Expectation of longer term trials is being played out in the background, companies fold up, succeed spectacularly, or go sideways for years. These details are not necessarily covered in much detail in the works on this topic to date.

Regardless, it is important to acknowledge here that many workers have contributed to furthering the understanding of how to handle uncertainties in our business. In this regard, the works of P.R. Rose, G.M. Kaufman, P. Newendorp, J. Schuyler, J.W. Harbaugh, J.H. Doveton, and J.C. Davis are much referenced and quoted in related literature.

SOME CONCEPTS AND REALITIES

At the outset it has to be stated that in all the Statistical trials described here, independence between trials is assumed. The conclusions derived here are unaffected by dependency assumptions. I also refer to Commercial Success and do not mention Technical Success because for a majority of companies Commercial Success is the main measure of exploration success. Again, the conclusions derived here are unaffected by whether we are looking at Commercial or Technical Success. The only requirement is to be consistent across the analysis. Only the shape of the Dice changes between the two measures of Success.

What is a Prospect COS? One good way of answering that question is to look at a Prospect COS as trying to work out the shape of the Dice which best describes the Prospect. E.g. in Figure 1 (a) at an early stage of looking at 5 different Prospects, the shapes of each of the Prospect Dice does not appear very clear. After further studies and work on these Prospects, it is possible to see the shapes of the Dice much better 1(b). Assuming that there is a Best Team using the best data and best technology to study the Prospects at a given point in time, then we arrive at the Hypothetical Best Estimation of the COS of those 5 Prospects 1(c). This is when you arrive at the 'Irreducible Risk' estimate of the COS for that point in time. Any team that under or over predicts the COS from this Best, will perform non optimally compared to the Best.

Regardless of how COS' have been conceptualised, the historical exploration results show the realities. Figure 2 (From Marita Bradshaw et.al) shows the unfolding of exploration in Australia from the early 1900s to 1998. The early lack of success till the 1980s is a telling and sobering statistic. Figure 3 (From Marita Bradshaw et. al.) shows that in the 60s and early 70s, commercial success rates in Australia were very low at around 10%. As exploration grew, with more wells drilled and hence additional geologic control, and the increasing use of modern technology followed by the push offshore to the more prospective basins, the average COS increased to about 30% in the late 1990s.

More recent statistics from Geoscience Australia (Figure 4) shows that the exploration success rate has gradually climbed to about 40%. A detailed look at the data (Figure 5) shows that the onshore success rate is about 45% and the offshore success rate is 35% by the mid-2000s. A major contributor to the onshore success rate is not only the use of modern 3D data but also the fact that the pools sizes for onshore commercial success are an order smaller than that for offshore. The costs for drilling and commercialising success in mature basins like the Cooper are also an order less than for offshore. Hence the chase for oil and gas ends up with closer spaced wells which leads to better understanding of the geology and hence a higher COS pre drill.

METHOD AND RESULTS

Although Geoscientists might not want to look at a Prospect COS as the shape of a Dice, it appears a good analogy for analytical thinking. In fact, it can be said that there is very likely to be no Prospect where it's COS is as clearly known as the shape of a Dice. Notwithstanding this fact, it is instructive to look at COS in this pure form to get a feel of the statistical underpinnings of this Perfect Predictor. Figure 6 shows the results of two experiments of throwing a 6 sided 'fair' dice 100 times. Success here has been defined as the outcome 1 as a success and failure is defined as the outcome of the numbers 2-6. For each throw, the number of throws to that point ***n*** are noted and each time a success with outcome of the number 1 occurs, a value of 1 is recorded for that ***n***th throw. The remaining outcomes with numbers 2-6 are assigned values zero. At each throw ***n***, the cumulative success value, say ***x***, up to that point is also calculated. Thus at each point ***n***, the average success rate up to that point is calculated by the formula ***x/n***. The first set of throws in Blue shows a 100% success rate at the first throw because the first throw came in as a success with the number 1. In the second set of throws shown in Purple, the first throw did not deliver success, so it starts with a 0% success rate. Both graphs however converge towards the average value of 1/6 = 16.7% in the long run after the 100 throws, showing that for all intents and purposes, the dice is 'fair'. However, note that long runs of no success can occur even in a simple dice. Especially note the purple graph where in succession, more than 20 throws did not deliver the success number 1. And it is worth reiterating that this is the result with an obvious simple six sided 'fair' Dice. Exploration realities are much more complex.

To illustrate a wider range of COS' than a Dice can afford, the Microsoft Excel spreadsheet has been used to create Perfect Predictors for 10%, 20%, 30%, 40% and 50% COS'. At the heart of it is Excel's random number generator function. Figure 7 shows the formulae and the workings for COS of 10% and 20% for the first 18 of 5,000 trials. Figure 8 shows the outcome of these COS computations. It is to be noted that the Excel random number generator does produce a 'fair dice throw' for all the COS' because despite early oscillations, in the long run (Fig. 8(a)), the COS' converge to the predicted values. However when we zoom into the first one hundred trials (Fig. 8(b)), the 'noise' in prediction become clearer for smaller number of trials. In the early period, the COS' criss cross each other before starting to settle by the 100^{th} trial. Figure 8(c) shows that within a window of the first 10 tries, there is a great deal of confusion between predicted and actual outcomes. And all of this 'confusion' in a 'Perfect Predictor'. This is only one of many sets of 5,000 trials that one could attempt. In reality, all of such simulations will tend to show differences in details but similar results to those presented here in the longer term. I have labelled the longer term behaviour as 'The Calm' and the shorter term behaviour as 'The Storm' and 'The Eye of the Storm' for obvious reasons.

Despite this 'confusion', there is another way of looking at the Probability outcomes which is more useful. Although it is difficult to predict when success is actually going to occur for any COS, this alternative method gives us a measure of the certainty with which we can expect a success after the drilling of a given number of wells. At the heart of it is the formula below in which the Probability of at least one success occurring after ***n*** number of wells for a given COS is calculated. E.g. for a COS of 20%, the chance of back to back failures after drilling 10 wells = (1-20%)^10 = 10.7%. Thus for a COS of 20%, the probability of at least one success after drilling 10 wells = 1 – 10.7% = 89.3 %. With this formula it is possible then to calculate the number of wells required say for 90% certainty of at least one success for each of the COS'. It can be any choice of % certainty but 90% seems a good high percentage number for practical purposes when someone is looking for certainty. 100% certainty requirements will drive the number of wells to infinitely large numbers and become impractical in real life situations.

Prob. = (1-(1-COS%/100)^^{n})*100

Figure 9 summarises the 'Risk' level for each COS%. Unless driven by other priorities, O&G companies with limited capital should play in the COS sector in which their ***chance of early success is higher***. This is mainly on the basis of smaller companies not being able to absorb the costs of early failures. As companies grow in their capital base and are able to afford more, materiality measures will force them to move up the 'Risk' curve from right to left. It is prudent for companies to understand where in the curve they want to play. This helps set team, management, board, and shareholder expectations. It will also be clear to the technical staff as to what type of prospectivity/ COS to focus on in their search for exploration opportunities. And very importantly, everyone understands that wells coming in dry is part of the statistics with 60-70% of wells on average worldwide expected to be non commercial. These statistics will obviously vary. There will be more dry wells in frontier and emerging plays and more successes in established trends.

COS – A NOTIONAL GUIDELINE

It is important that everyone involved in our business has some idea of the controls on COS'. It is truly difficult for everyone, except the technical team to have a good handle on the COS'. COS' are based on the confidence in the presence of favourable factors in finding commercial hydrocarbons in a given Prospect. This confidence is based on the strength of the geological evidence used to predict the presence of these factors. The overall COS is obtained by multiplying the chance of the presence of each one of the component parameters for the presence of a commercial hydrocarbon accumulation. This process can get quite complicated but is simplified here for illustration purposes with three component parameters, Source, Reservoir and Trap. It is understood that Source has to include, amount/quality/expulsion/migration efficiency considerations and reservoir has to include type/extent/thickness/quality considerations and trap should include seismic definition quality and top/bottom/lateral/fault seals/preservation considerations. The probability of favourable occurrence of each of these component parameters is dependent on the distance from the nearest relevant well/s that gives such information. Generally speaking, geologic models for each of these parameters project to various distances from the nearest relevant well control depending on the geology. E.g a 500m source rock has the probability of projecting over a much wider area than a 20m source rock within small rift basins. Similarly, a thick 100m braided system sandstone has a better chance of projecting greater distances than a thin 10m thick fluvial channel.

Figure 10 shows that when all three parameters are less certain than not at 40% chance of presence of each, the overall COS is a low at 6% (A). This is generally true of rank wildcat basin wells far from relevant well control. Usually, distances are in the 50-100 km range from nearest relevant well control. In these cases, global analogues might help in increasing the COS. Obviously 100% COS would be when you twin a well at Zero distance. So, between 5% - 100%, we can build a notional model of distance to nearest relevant well control vs COS for a given basin or sub basin or geologic province. Generally, when the constituent parameters have a chance of occurrence of 50%, with overall COS of 13% (B), it would require that we have a relevant well less than 50-100km. To obtain greater confidence in the presence of favourable constituent parameters and to get into the 22% (C), 34% (D) and 51% (E) range, it would generally require closer and closer relevant well control.

This notional guideline is not exact and fixed everywhere but is one that can be guideline as a starting point. If the nearest relevant well is 50km away, it does not categorically rule out a prospect having a COS of 25-30%. All it says is that the geological model and story to explain why that can be true has to be put together cogently to be accepted. This notional model also helps managers and other stakeholders who are not directly involved in the technical analyses to ask questions so that they can better understand the risk elements. At the end of the day, the more educated each one is, the less the probability of misunderstanding the outcomes of exploration results.

CONCLUSIONS

The reality of oil and gas exploration worldwide is that despite best efforts, companies are going to be drilling 60-70% non commercial wells. Other than the world's major oil companies who may have statistically significant wells to be drilled over a corporate horizon of between 1-5 years, many companies, especially the very capital constrained small ones are going to continue to drill limited wells. COS' which by their intrinsic nature are long term expectations, do clash against the near term certainty requirements of small companies whose survival and early growth depends on early successes. Figure 11 (from Richmond Energy

Partners) shows the predrill prognosed COS vs the actual commercial success rates of a couple of hundred wells drilled worldwide by a select group of 40 companies between 2009-2013. It is evident that when the size of the sample is sufficiently large, although not exact, the pre and post drill results are within limits of expectations. So, most geoscience teams in this sample are generally within the mark in their predictions. The confusing aspect is what has been described above as early statistical noise when the sample size is small.

It is hoped that this paper has conveyed the vagaries in the unfolding of exploration failures/ successes. Despite the intrinsic difficulty in predicting exactly when an exploration success can occur, Figure 8 shows that companies can keep to the COS range that gives them the best chance of early survival based on expectations of how many wells need to be drilled to obtain 90% certainty of at least one success. When all of the players in the game, from the exploration teams, to management, to the board and shareholders, are fully informed of what to expect from an exploration program, there is a better chance of the whole process of exploration being made smoother, with companies holding their set courses, and faith being maintained in the teams for the longer haul. This would also aid in maintaining overall morale in a company which is in an industry where on the average, less success than more is the norm.

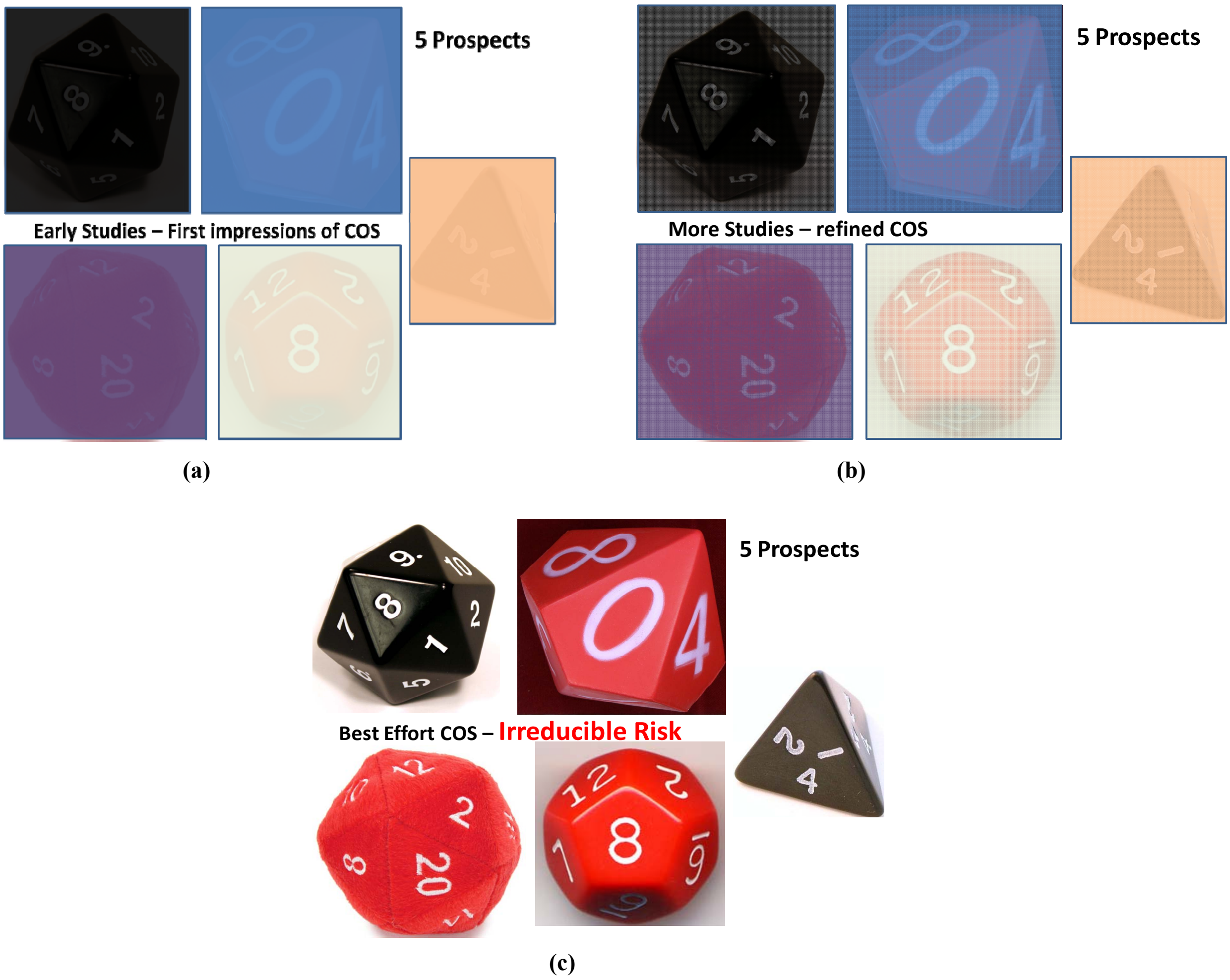


Figure 1: Analogy of 5 Exploration Prospects being viewed as 5 Dice of varying shapes at different phases of Study before actual drilling. (a) At an early stage, the COS' are vague and unclear; (b) After early study, the COS' are clearer, the prospect still remains attractive but it is felt that the COS can be better refined through more data, work and effort; (c) After using all existing data, expertise & technology, the COS' appear as clear as they ever can be at that time — this is the stage of 'Irreducible Risk where the Risk cannot be reduced anymore given the limitations of data and expertise at that given point in time.

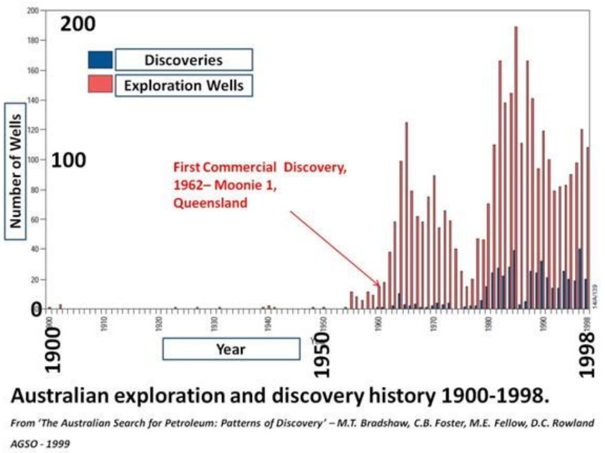


Figure 2: Exploration in Australia did not take off until the 1960s with the first commercial discovery onshore in 1962. Early success rates were low until exploration expanded with more wells drilled, improved technology used, and the push to the more prolific offshore basins.

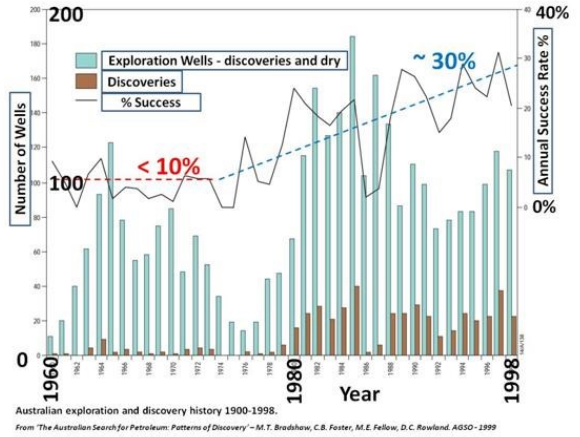


Figure 3: By modern standards, early exploration in Australia, especially from the early 1960s to the early 1970s had low exploration success rates of <10%. However, by the late 1990s, success rates reached respectable levels of 30%.

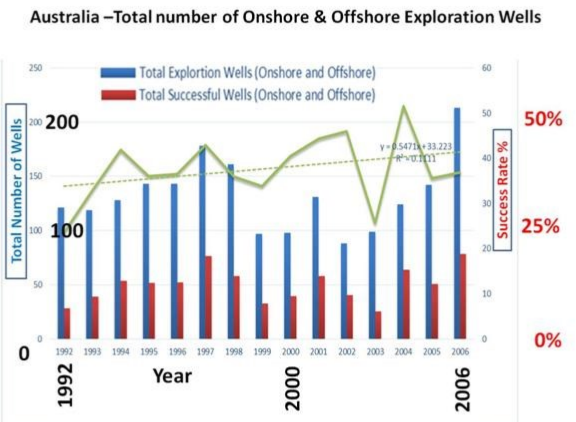


Figure 4: More recent exploration performance graph drawn from Geoscience Australia 2006 O&G Statistics. Success rates crept from~ 35% to 40% in this period.

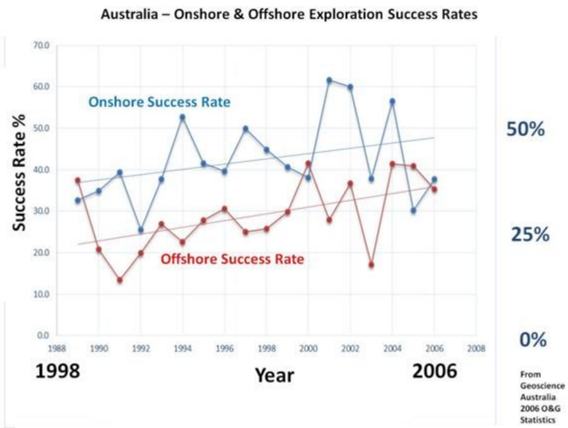


Figure 5: Detailed split shows that onshore exploration rates have been about 10% better than offshore exploration rates in this period

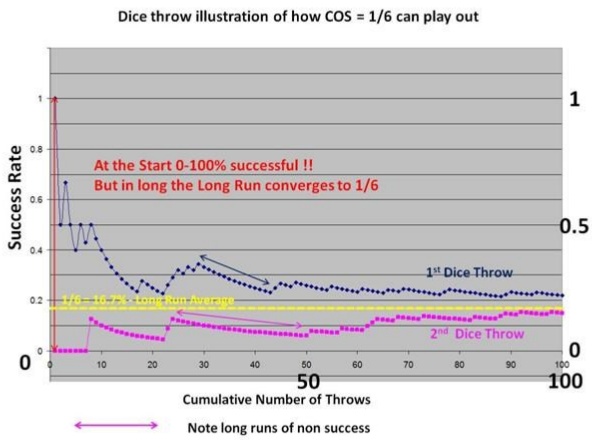


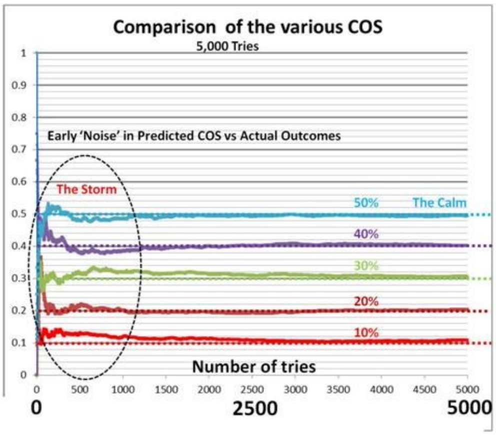
Figure 6: Graphs of two sets of 100 dice throws representing average Success Rates from 'Perfect Predictions' of COS of 1 out of 6 (16.7 %). Note that the average rates of success settle to the predicted success rate only later in the throws, and even in 100 throws, does not achieve the 'Perfect Prediction' of 16.7 %.

Excel Simulations of 'Perfect' 10%, 20%, 30%, 40% & 50% COS

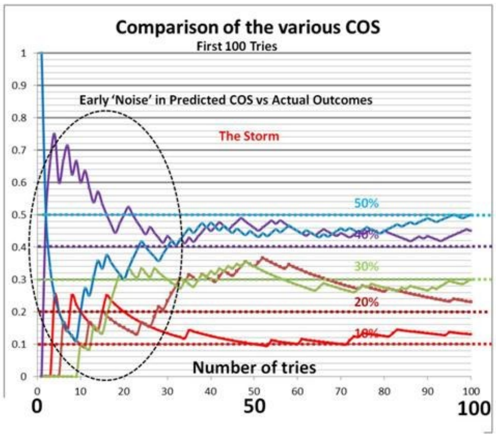
Excel Formulae are =RANDBETWEEN(1,1,000,000) & =IF(B3>900000,1,0)

Number	10% Probability		Cum. Success	Average Success Rate	20% Probability		Cum. Success	Average Success Rate
1	932542	1	1	1	980917	1	1	1
2	552313	0	1	0.5	41581	0	1	0.5
3	760455	0	1	0.333333333	18279	0	1	0.333333333
4	83314	0	1	0.25	309729	0	1	0.25
5	509886	0	1	0.2	458169	0	1	0.2
6	798431	0	1	0.166666667	11805	0	1	0.166666667
7	920342	1	2	0.285714286	194803	0	1	0.142857143
8	536223	0	2	0.25	458494	0	1	0.125
9	941669	1	3	0.333333333	598328	0	1	0.111111111
5,000 10	626394	0	3	0.3	443374	0	1	0.1
11	915363	1	4	0.363636364	846570	1	2	0.181818182
12	292584	0	4	0.333333333	464031	0	2	0.166666667
13	66654	0	4	0.307692308	124078	0	2	0.153846154
14	967323	1	5	0.357142857	506374	0	2	0.142857143
15	55071	0	5	0.333333333	849331	1	3	0.2
16	440610	0	5	0.3125	492187	0	3	0.1875
17	472513	0	5	0.294117647	847981	1	4	0.235294118
18	701626	0	5	0.277777778	833189	1	5	0.277777778

Figure 7: Sample of the Excel COS Simulation Spreadsheet using the Random Number Generator function.



(a)



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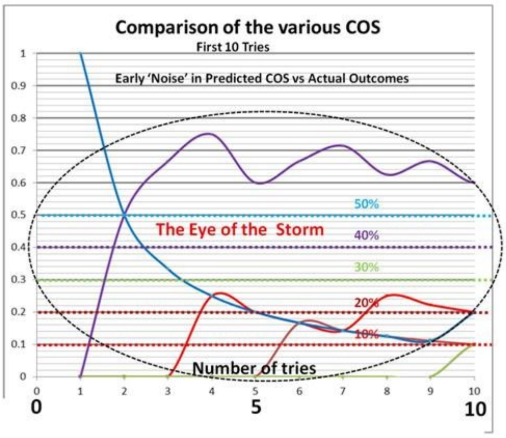

(c)

Figure 8: Results of simulations for 10%, 20%, 30%, 40% & 50% COS using Excel Random Number Generator. (a) shows outcomes to 5000 trials confirming that the simulation is a Fair Simulation because the predicted COS converges to the actual in the long run - 'The Calm'; (b) Zooming the first 100 trials shows the early criss crossing of predictions and illustrates the statistical 'Storm' and noise in this early part of the trials; (c) Zooming the first 10 trials shows total confusion between the various predictions and actual outcomes. What is labelled here as 'The Eye of the Storm'.

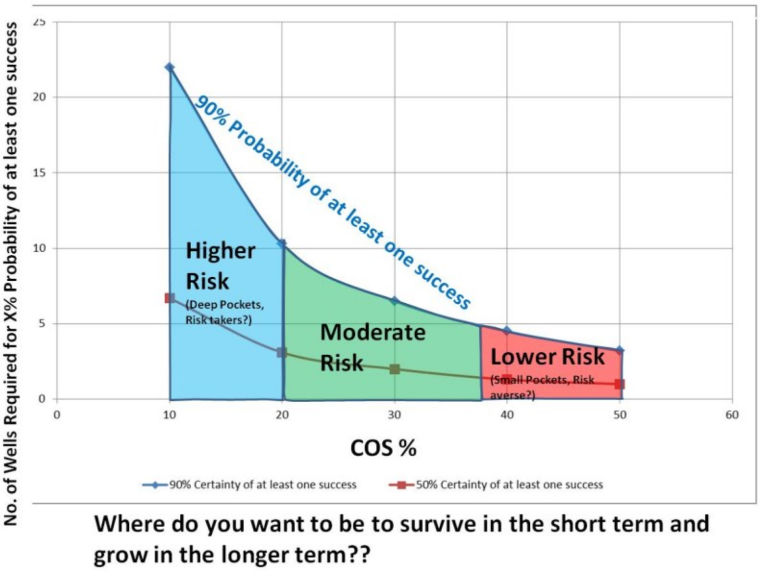

Figure 9: The challenge for O&G companies is to determine the level of risk they are willing to take. The ability to survive is determined by the level of risks companies take. The COS' of prospects chosen for drilling determines this survivability.

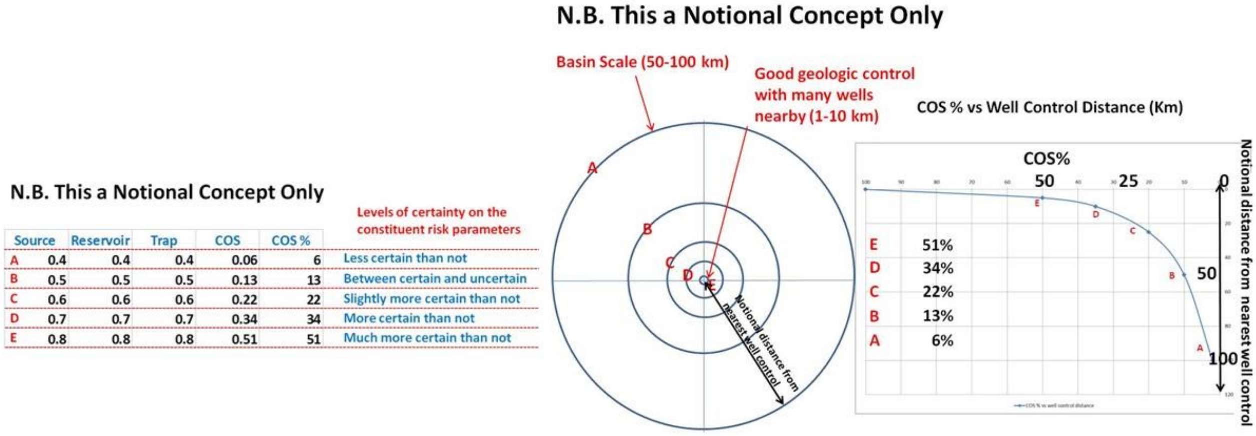

Figure 10: The proximity of relevant well control determines the certainty with which the presence of the constituent COS parameters Source, Reservoir and Trap of a given Prospect can be predicted. Generally speaking, the further the relevant well control is for evaluating a Prospect, the lesser the COS of the prospect. Undrilled basins/ sub basins which do not have local well control within 50-100 km are expected to have COS' of less than 10%. The COS should improve with closer relevant control as suggested graphically above. Obviously, this is geology dependent and other relevant data, analogues and good geologic models can change this relationship.

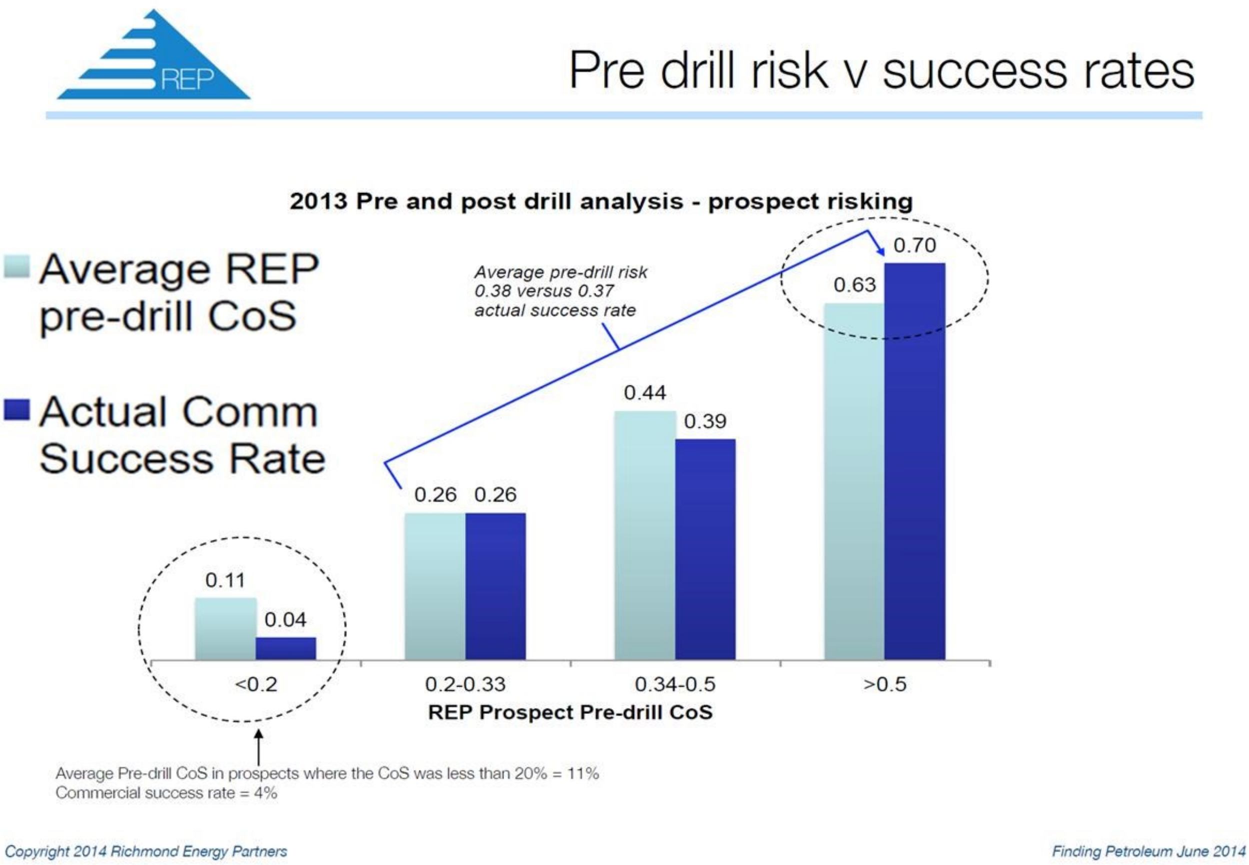

Figure 11: This study by Richmond Energy Partners shows the pre drill and post drill success rates of the results of exploration drilling between 2009-2013 from a select group of 40 companies around the world. Given that the sample is large (about 200 wells), the pre drill and post drill predictions are within 5-7% of each other. This illustrates the fact that although 60-70% of the exploration wells end up being non commercial, if the sample size is large, COs predictions work reasonably well. The challenge is the confusion on prediction of success when the sample size of wells drilled is small. This is typical of the smaller companies in our business.

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This paper would not have been possible without the patience of my family, especially my wife Theresa who has put up with my many hours of perusing over various forms of graphs and thoughts to present this paper. But it would especially be incomplete without thanking, our then young daughters Priya and Sharmini who in the Mumbai Hotel room assisted me with throwing Rupee coins and Dice when I was writing the early part of this paper in the mid 2000's.

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