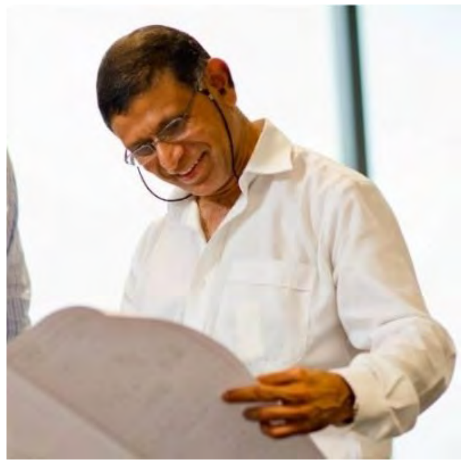
Exploration Chance of Success Predictions - Meanings, Perplexities and Impact

by Balakrishnan Kunjan



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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 article, the various probabilistic aspects of exploration expectations and outcomes are reviewed. Within the context of the intrinsic difficulty of not being able to guarantee any specific success, it will be shown how companies can choose the COS range inside which they should explore, to ensure survival and hence ensure sustainable growth over the longer term within chosen aggregate wells/ prospects drilled.
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.

Mr Kunjan is visiting Oslo in September

SPE Oslo section would like to invite everyone interested in understanding the concepts of exploration chance of success predictions to come listen to Mr. Kunjan on the 21st September.

"I'm hoping that my experiences gained from small, limited funds companies in the Aussie/ Australasian region provides the right masala mix for some of the companies operating in North Europe. Or I might find my curry offering too hot and spicy up North!!'

Further details will be announced.

Introduction
What does a person making a probabilistic prediction actually mean? What does it mean to the person/s to whom this prediction is being conveyed? What are the impacts of the understanding/ misunderstanding between the probabilistic predictions made by the predictor and the person/s receiving these predictions?
Having written on this subject, presented it many forums, and debated it, the author has found it to be a rather 'slippery' subject that has to be handled as tightly as possible. It is useful to discuss probabilistic predictions in a generic way first, then take it to probabilistic prediction of Geologic Chance of Success (GCOS) and then to Commercial Chance of Success (CCOS).

Basic Probabilistics
A probabilistic prediction appears to have a real and at the same time unreal feel about it which might best be described by predicting the outcome of the throw of a six sided dice. For most people, the real part of the prediction would be the number put on the probability of a given outcome, say the number one on the dice, after one throw. That number which has a feeling of reality to it is 1/6 or 16.7%. ***The unreal component of such a prediction is that the predictor can never know exactly when that expected outcome number one will occur in reality.***

Figure 1 shows the results of two experiments of throwing a 6 sided 'fair' dice 100 times. Success here has been defined as the outcome 1 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 nth 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.* Figures 2(a), 2(b) and 2(c) show 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 (Figure 2(a)), the COS' converge to the predicted values. However when we zoom into the first one hundred trials (Figure 2(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 100th trial. Figure 2(c) shows that within a window of the first 10 tries, there is a great deal of confusion between predicted and actual outcomes. And to think that all of this 'confusion' can occur 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

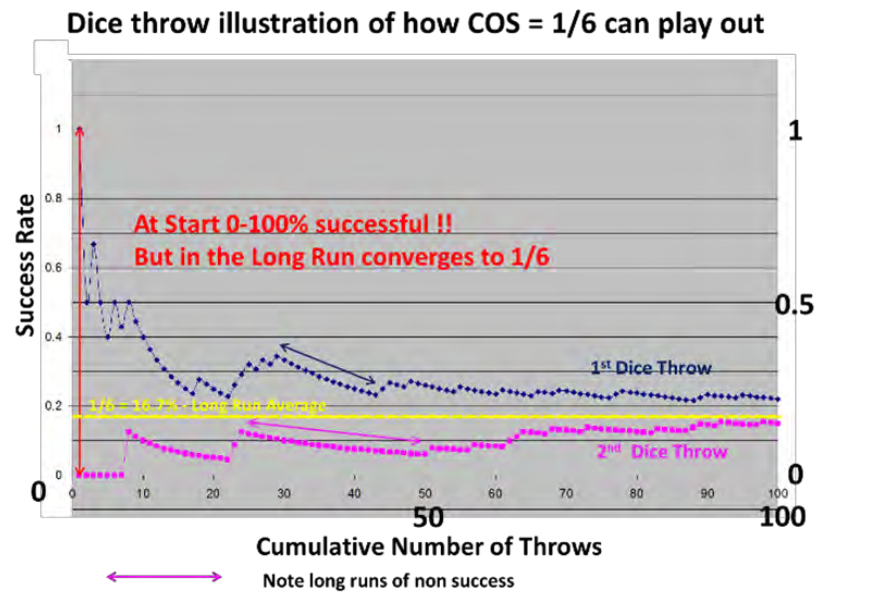

Figure 1[+]. Graphs of two sets of 100 dice throws representing average Success Rates of 1 out of 6 (16.7 %). Note that the average rates of success settle to the predicted success rate only later in the throws, and even in 100 throws, does not achieve the 'Perfect Prediction' of 16.7 %.

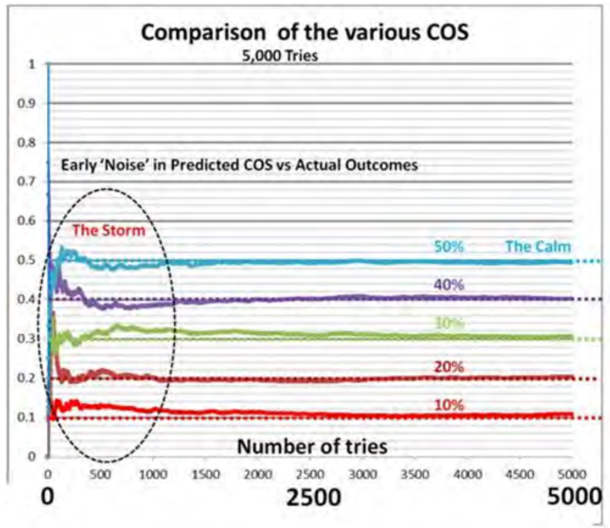

Figure 2 (a)

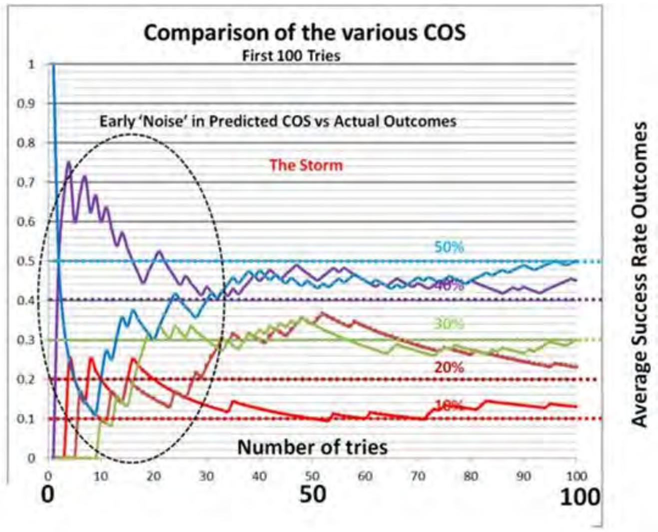

Figure 2 (b)

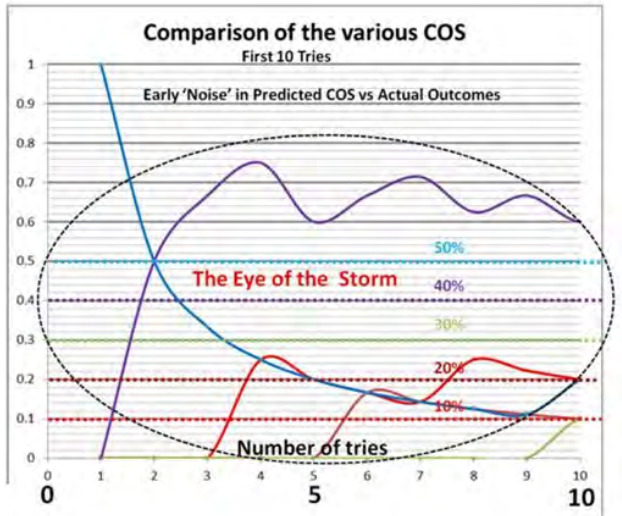

Figure 2 (c)

Figure 2. Results of simulations for 10%, 20%, 30%, 40% & 50% COS using Excel Random Number Generator.

Figure 2(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'.

Figure 2(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.

Figure 2(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'.

* Please refer to my paper "Exploration Chance of Success Predictions – Statistical Concepts and Realities" for examples of how these outcomes are calculated using Excel.

	Source	Reservoir	Trap	COS	COS %	Levels of certainty on the constituent risk parameters
A	0.4	0.4	0.4	0.06	6	Less certain than not
B	0.5	0.5	0.5	0.13	13	Between certain and uncertain
C	0.6	0.6	0.6	0.22	22	Slightly more certain than not
D	0.7	0.7	0.7	0.34	34	More certain than not
E	0.8	0.8	0.8	0.51	51	Much more certain than not

Figure 3. This is a simplified form of GCOS evaluation just to illustrate how the constituent components impact the overall GCOS. In reality, in most cases, the Trap is better understood than the other components, especially if seismic imaging is good. Source and reservoir generally tend to be more challenging in terms of achieving improvements in the GCOS.

tend to show differences in details but similar results to those presented here, in the longer term. The longer term behaviour has been labelled as 'The Calm' and the shorter term behaviours as 'The Storm' and 'The Eye of the Storm' for obvious reasons.

G&G Evaluation - Geologic Chance of Success (GCOS)

The Geologic Chance of Success (GCOS) is the pre drill probability that the petroleum geology model we put forward for a given prospect is successful. The Geologic Chance of Success (GCOS) is obtained by studying the chance of presence/ effectiveness of source rocks/migration, reservoir rocks, seals and trapping configurations. The details of how GCOS is calculated can vary and differs between companies. It is presented in Figure 3 in a simplified form and can be very much more involved in detail depending on who is doing it. It is recognised that this subject is a big topic in itself. At the end of all these studies, the GCOS represents the probability that a Prospect, if it contains hydrocarbons, will have a Field Size Distribution as discussed later below.

Presented in Figures 4 and 5, in a simplified manner, is the case of fictitious Prospect A in which the title 'Morphing of the Dice' illustrates the changes in the GCOS as we proceed through the various stages of prospect evaluation.

Our first impressions of the GCOS of a Prospect can either be lower or higher from our very final one post all the analyses we intend to do on it. This fictitious example shows how when progressing from Early to Middle to Mature Stage Evaluations, the GCOS increases, i.e. the number of sides to the dice decreases.

Prospect A, a fault controlled structure, is defined by only five 2D lines two of which pass through wells. At the very earliest stage, quick structural maps on key horizons are made. In conjunction with this, a rapid evaluation of the wells 1 & 2 and any wells outside

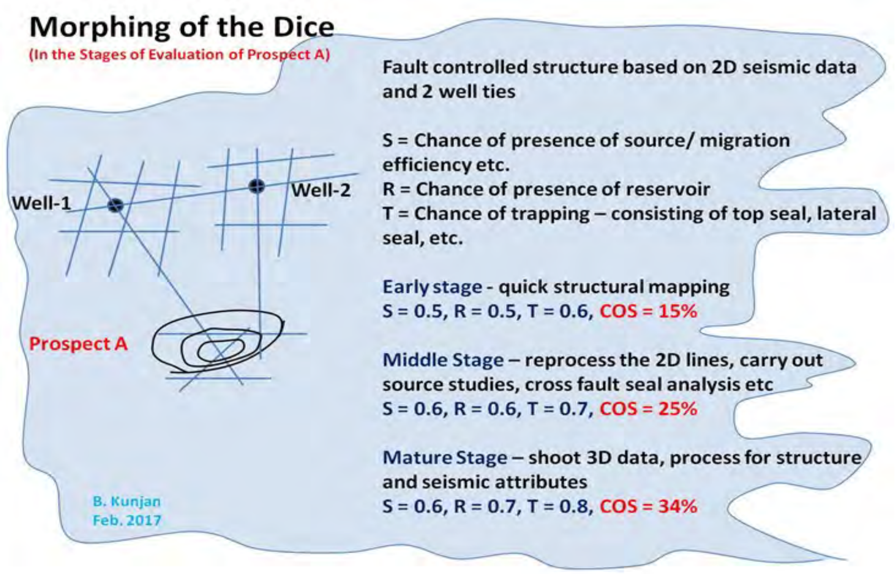

Figure 4. The GCOS of a given prospect changes at various phases with additional analyses and data.

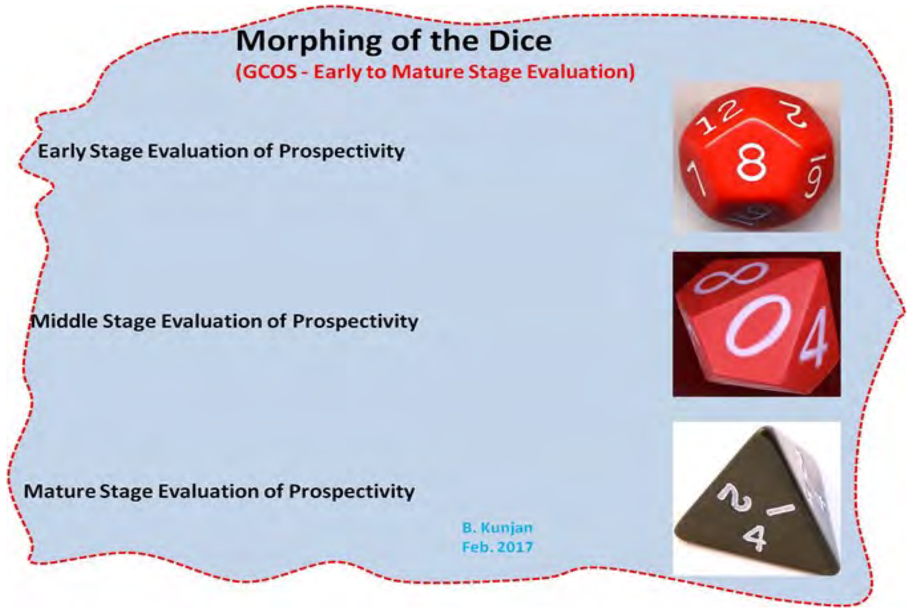

Figure 5. This change of the GCOS over the different phases of evaluation is illustrated with a correspondent change in the shape of the dice representing the probabilities (Note: the dice shapes are only illustrative and not meant to represent the GCOS numbers in Figure 4).

the immediate area are carried out which will give an idea of presence, quantity, maturity, etc. of the source rocks, the presence and effectiveness of reservoir rocks, and the presence and quality of sealing rocks. If more regional data is available, further analyses can be done including the evaluation of the presence/ effectiveness of source and migration pathways, reservoir and seal rocks etc.

Early lack of knowledge usually should lead to a more cautionary, lower GCOS. At the Middle Stage, usually, reprocessing of seismic data with emphasis on structural, stratigraphic and possible seismic attributes is carried out. At this stage, the GCOS has the possibility of either going up or down from the initial GCOS but in this case the GCOS increases because the structural definition, especially of the fault improved and the ability to map the reservoir units more confidently increased with better seismic data. In the Mature Stage, 3D seismic data which is not necessarily a must in all prospects, was acquired specifically to enable further enhancement of structural/ stratigraphic definition and also for seismic attributes that might help define reservoir and fluid content better. And in this case, structural, stratigraphic and fluid content understanding was improved with the 3D data.

The GCOS numbers offered, though fictitious, are not unrealistic in a real world setting. In fact, one of the valuable skills of seasoned explorationists is the ability to predict ahead of time how we expect the GCOS to move from Early to Mid to Mature evaluation of a given prospect. Each stage of the evaluation involves the spending of money and management would need justification for spending additional money on the basis of Value of Information.

G&G Evaluation - Prospect Field Size Distribution

The other part of the evaluation of prospectivity is the Field Size Distribution which is illustrated in Figure 6. It is basically the measure of the physical size of the hydrocarbon volume expected in a prospect. The most important component of this measure is the mapped size of the prospect in terms of the Gross Rock Volume (GRV) within the structure that could potentially hold hydrocarbons.

The truth here is that an exploration well is not promising any one particular Field Size but a Probability Distribution of outcome of Field Sizes prior to drilling. But any pool size discovered will give very important information on the elements of the Petroleum System. As you can see, the input into the Monte Carlo calculations has many elements of the Petroleum System that goes into it.

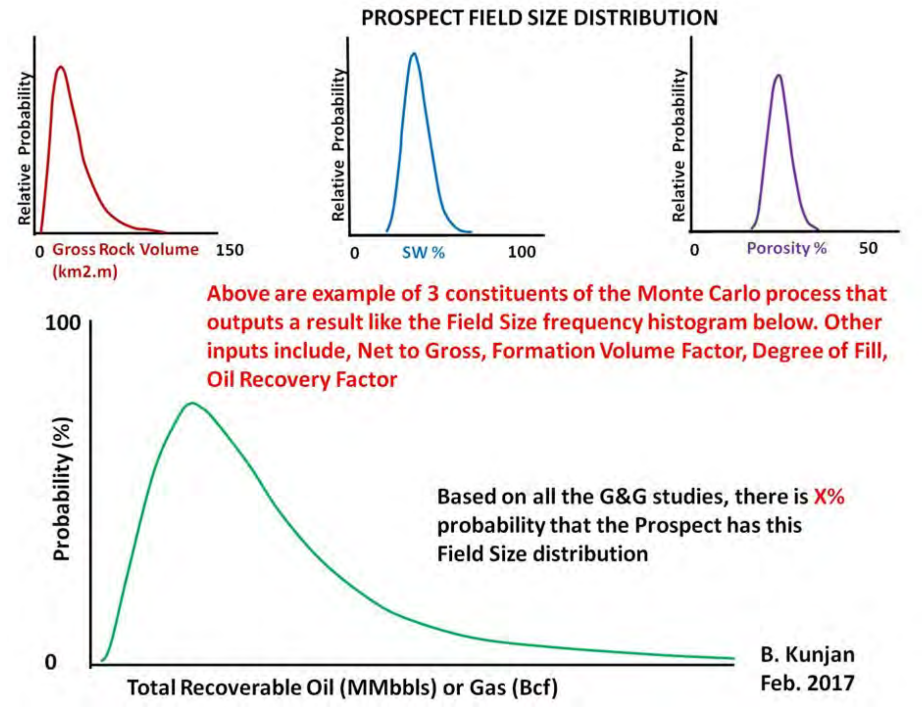

Figure 6. The Field Size Distribution for a given prospect is determined by input parameters that include Gross Rock Volume (GRV) that is derived from the maps of the prospect, and the reservoir porosities and water saturations obtained from nearby well control. The common method of estimating probabilistic reserves is to utilise the Monte Carlo method using all the input parameters described to output the probabilistic reserves curve shown .

Commercial Chance of Success (CCOS)

In parallel, or post the G&G evaluation, a team of engineers and economists working together will help figure out whether a discovery can be made commercial. Considerations will include the location of a discovery, distance from infrastructure, development methodology, capex/ opex, oil/gas price/ currency movements, etc. Based on these considerations, it is possible to work out the Minimum Economic Pool Size (MEPS) which would make a discovery commercial in that location. Based on the G&G team's predicted field size distribution, it is possible to obtain the probability of finding a field with at least that MEPS for a given prospect. The Commercial Chance of Success (CCOS) is a product of the GCOS and the probability of finding at least the MEPS in the given prospect. The exact details of how all of this is done varies from company to company. It is presented in a simplified manner here for illustration purposes.

It has to be noted here that a company that chooses to drill a well targeted to prove a Commercial sized field with the first well on a prospect by drilling down dip is making a very important decision in this regard. The implication is that it is willing to accept the consequences of not knowing the information that would be obtained from a sub commercial accumulation up dip in a more crestal position.

With this approach of going for a Commercial success in the first well, even an extraordinary exploration team cannot prove its capabilities in terms of finding hydrocarbons. Because the GCOS is not only about finding Commercial hydrocarbons. And more importantly, if a company has plans to continue drilling in an area, the team will miss important petroleum systems information by not drilling optimally for this purpose. This has to be a calculated risk by the company. At the end of the day, it also ties the hands of the Explorationists in terms of limiting the crucial data that they have to gather for the longer term.

Exploration Realities and Challenges

Pre drill chance of success (COS) predictions appear to mean different things to different people. Although on the surface most professionals involved in oil and gas exploration appear to have an understanding of COS, when venturing deeper into what it actually means, there appears to be confusion both in the conceptualisation and the communication of it's meaning to others. It is the author's observation, having worked with various teams within various organisations around the world that this confusion leads to ineffective approaches at exploration, inefficiencies in exploration execution, anxieties from the actual outcomes from well results, negative impact on team morale, and eventually loss of shareholder value.

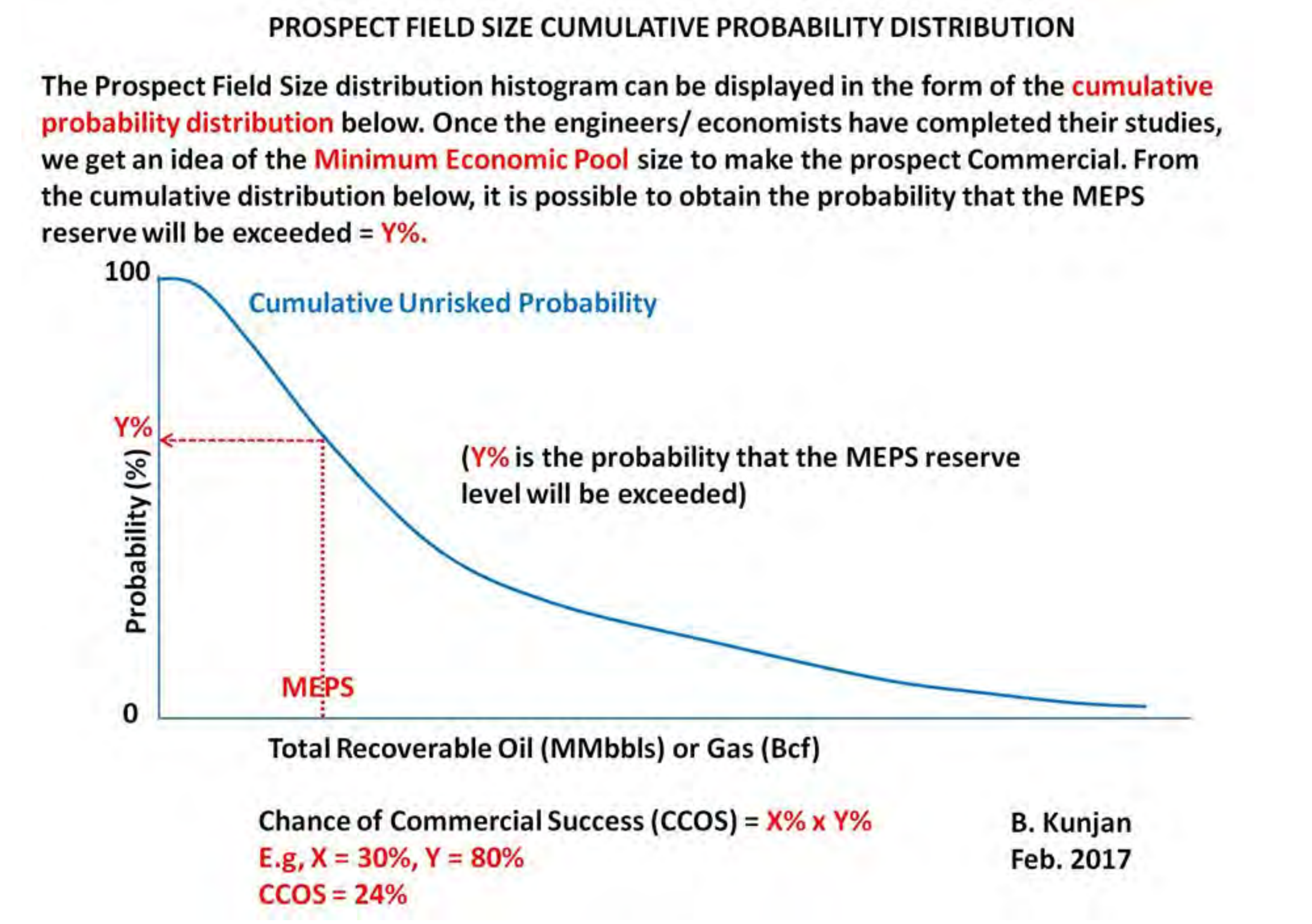

Figure 7. The Commercial Chance of Success (CCOS) is obtained from the GCOS and the probability of finding at least the Minimum Economic Pool Size of hydrocarbon reserves

By nature, Geoscientists like to believe that their methodologies are objective. However, at the end of all scientific analyses, a COS prediction is still subjective. Those who have worked in teams trying to obtain consensus on a COS would have an understanding of this. This subjectivity is also revealed by the different valuations that different teams/ companies make in block bids, though it is recognised that strategic considerations do have an overlay on this.

Once a COS is 'finalised' pre drill, say 30%, it is in a sense fascinating how a negative drill result still takes everyone by 'surprise'. This, despite the pre drill knowledge that on a single well basis the well has 70% chance of a negative outcome. There are real examples of negative impacts on team morale and the structures of teams.

Figures 8 shows the actual exploration success rates from a worldwide sample. It is sobering to note that worldwide our commercial success rates are averaging between 30-40%.

Much of the troubles we face seem to stem from the fact that well results are seen as single events, when actually, in an essentially

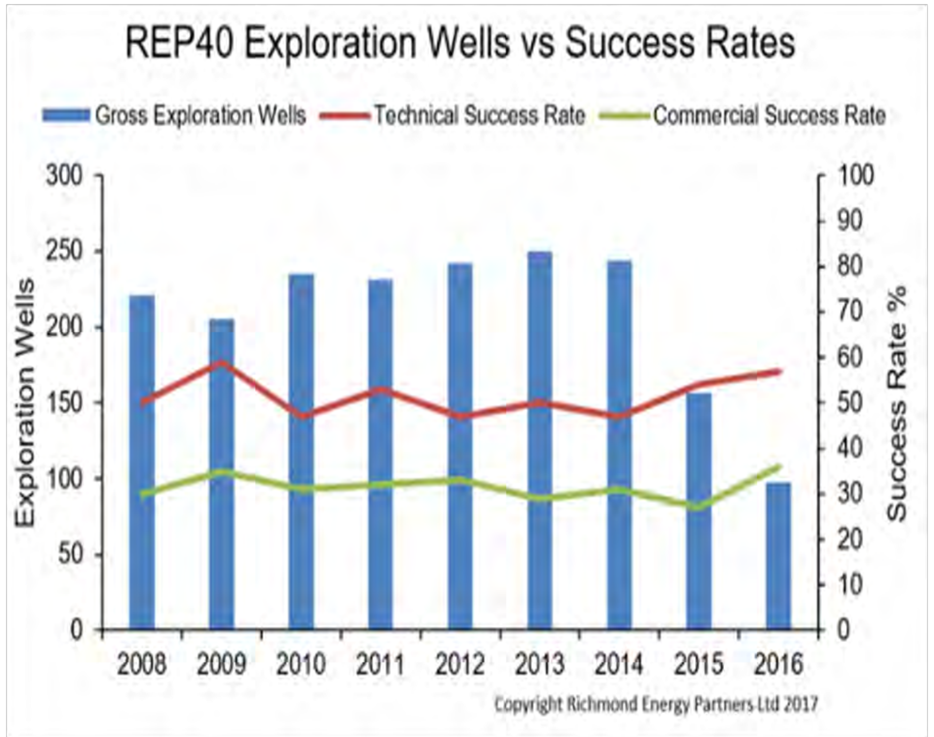

Figure 8. These results show that 60-70% of discoveries were not commercial over the period 2008 to 2015, but it appears that commercial success rates started to rise in 2016 as a result of high grading of portfolios and the drilling of 'less risky' exploration wells. The figure was offered by Richmond Energy Partners via personal communication.

probabilistic world of random trials, well results should be seen in aggregates. Figure 9 shows an alternative way to look at COS'. The line annotated as "The Survival Frontier" shows the number of wells required at any given COS for 90% certainty of at least one success.

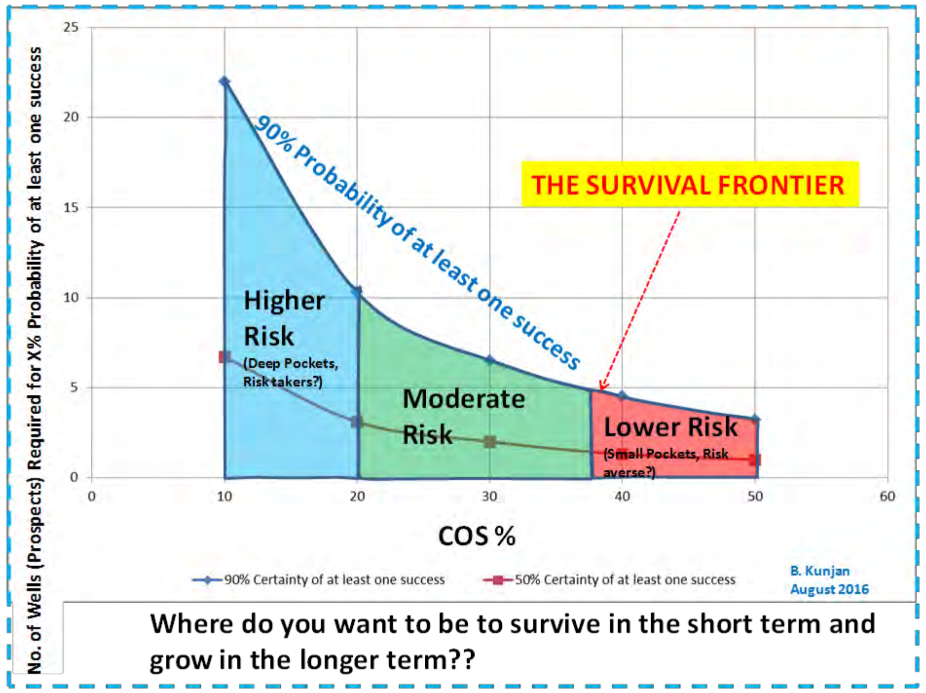

Figure 9. This graph shows an alternative way to look at COS'. The line annotated as "The Survival Frontier" shows the number of wells required at any given COS for 90% certainty of at least one success.

Small to medium size companies typically have limited budgets over their 0-5 years corporate horizon. The ability to fund a given number of wells should guide where each company wants to play, to initially survive, then to grow. It is suggested that if funding is only available for 3 wells, then these companies should stick initially to wells with COS = 50%. Typically, lower risk would mean lower reserves. When the corporate budget increases, then materiality considerations may encourage a company to move 'up the risk curve'. Note that at COS = 25%, you need 8* wells for 90% certainty of at least one success. It is important also to note that the 3 or 8 wells referred here does not mean sequential drilling regardless of outcome of any given well. If any well result downgrades any future prospect, then it is suggested that the company drills the next alternative acceptable COS prospect which may take some time to firm up in the same play or elsewhere.

Although risk, costs and rewards must be considered, the assumption made here is that survival is of utmost importance for small companies, while building up materiality. Any form of comparing prospects on risk weighting or on the basis of EMVs is not discussed here because 'expectations' are only achieved after a statistically significant number of wells are drilled. It is implicitly assumed here that all wells drilled will make enough money to cover all costs, i.e. the wells are all of positive NPV in the success case.

Conclusion

There exists a great deal of confusion on the conceptualisation, communication and interpretation of Chance of Success predictions in our exploration business. These challenges are non trivial and do affect the efficiency and effectiveness of the exploration effort to various degrees in various companies. Given the probabilistic nature of our business, there has to be the greatest clarity in what we mean by our predictions and how we operate within this realm of uncertainty. The better the flow of understanding at all levels, the less the losses, and more the gains from our exploration effort for the money expended.

In summary, with a broader perspective of looking at exploration as an aggregate effort rather than a well by well effort, a more efficient and effective exploration program can be laid out and executed, thereby increasing shareholder wealth at the same time as keeping company morale intact.

Acknowledgement

This article is a further development of a paper entitled "Exploration Chance of Success Predictions – Statistical Concepts and Realities" presented at the ASEG-PESA Conference in Adelaide on August 2016. (http://www.publish.csiro.au/EX/pdf/ASEG2016ab150).

There are many who have contributed to this paper via discussions and peer review and are acknowledged in my paper. However, I take full responsibility for the contents of this paper.

Figure 1[+] - This graph is from my consulting days in India where in trying to convey these concepts, I enlisted the assistance of our then young daughters Priya and Sharmini, who in a Mumbai Hotel assisted me with throwing Rupee coins and Dice when I was writing the early part of this paper in the mid 2000's. I remain indebted to them for assisting in this experiment.

This paper also includes many of the concepts developed by the author in LinkedIn articles since December 2016.

About the author

***Bala Kunjan** has 40 years G&G experience in exploration and development across the Oil and Gas Industry in Asia-Pacific Basins of Malaysia, Indonesia, India, Australia, New Zealand, and the USA. He has worked within integrated teams of geologists, geophysicists, and reservoir engineers, leading to significant field developments and discoveries such as the Ravva Oil Field (India), Krishna Godavari Basin (East Coast India) Deepwater Discoveries, East Spar Gas/Condensate Field (Carnarvon Basin, Australia), Tui Oil Field (Taranaki Basin, New Zealand), Casino/Henry/ Netherby Gas Fields (Otway Basin), Yolla Gas/ Condensate Field (Bass Strait), many Cooper Basin Gas and Oil Fields and the Oyong and Wortel oil and gas fields in the Madura Straits, Indonesia. He has been noted for mentoring younger geoscientists since 2004. His core area of interest is in visualizing/communicating exploration risk, and planning for sustainable long term success through anticipated probabilistic outcomes from given assets/ portfolios. He has a BSc Hons in Geophysics from the Science University of Malaysia, Penang, 1977 and an MBA from the Australian Graduate School of Management (AGSM), University of New South Wales, Australia, 1990.*

Having started his career with Esso in Malaysia (1977-1985), he has worked as an employee as well as a consultant with various companies including Delhi Petroleum (Adelaide), Santos (Adelaide), Western Mining (Perth), Command Petroleum/ Cairn India (Sydney/Edinburgh/Chennai), Reliance Industries (Mumbai), AWE (Sydney) and Drillsearch (Sydney). Currently he works with Cue Energy in Melbourne.

Bala is a member of the AAPG Visiting

* If COS = 25%, Chance of back to back failures drilling 8 wells = (1-25%)^8 ~ 10%. Therefore, the Probability of at least one success after drilling 8 wells is 90%. You could choose to drill higher COS numbers as at 50% COS where the 90% chance of at least one success is delivered with 3 wells.