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EALine of Sight Exploration
Managing Uncertainties for Exploration Success – Concepts, Challenges and Implementation*

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Introduction

Managing uncertainties in our oil and gas exploration business goes well beyond technical analyses. The intent of this paper is to show how factors outside the technical effort can affect the outcome of exploration campaigns. Predictions made by teams affect investment decisions but how this analysis is conveyed to other stakeholders has a significant impact on exploration decisions and hence the outcomes of programs.

All of us involved in the exploration effort including those outside the team have to have a clear line of sight between the present state of knowledge and where the company wants to go in terms of value creation (Figure 1).

At the core of all exploration is the statistics of expected outcomes. In the author's view there is not much in existing literature that specifically addresses the statistics of limited trials campaigns. Much of the existing math of evaluation includes concepts like EMV which inherently assume large number statistical trials. On a limited trials basis, including the drilling of just one well, it is impossible to convey any certainty of outcomes. E.g. if a prospect has a Geologic Chance of Success (GCOS) of 25%, it equally means a 75% chance of failure. However, if we drill a series of exploration wells in a campaign, just the collection of throws of the exploration dice would increase the chance of at least one success. This process, though not guaranteeing success, shows the statistical tendency towards increased success. These are key facts that are probably known by some but not appreciated by many. Whether all levels of workers and all the stakeholders understand this critical issue can determine whether a company modifies plans or quits from what is a very carefully thought out drilling campaign. Or stays the course.

In the author's experience, in many occasions, there is a disconnect at all levels between the hope of drilling successful wells on each prospect and the underlying reality that success is not statistically guaranteed when drilling any given prospect. This can lead to many short sighted and ill-informed decisions. It is the intention of this paper to capture the whole process starting early in the risking process right through to visualization of economic benefit creation at various stages of the campaign. Keys are offered here that can provide at each instant of the exploration process, analyses of how eventual success probabilities may shape up, starting predrill and right through the exploration process. This approach to the analysis is especially important to companies with limited capital resources that can only drill a handful of wells.

How Best to Present Expectations on Exploration Outcomes

It is the author's experience working with many companies that the technical teams have had difficulties in conveying the concepts of uncertainty between themselves and also to others. Following are some key concepts that may help. In the example shown in Figure 2 of a 6 independent wells campaign, with the COS numbers calculated based on a simplified Source/ Reservoir/ Trap probabilities calculation, there are four possible outcomes we can display. These are the Probability of at least one success, the Probability of at least one failure, the Probability of back to back success, the Probability of back to back failure. The author has found it useful to use the first curve, i.e., the Probability of at least one success because in reality, this is what most of the stakeholders want, articulated that way or not. Thus, in the example below, we can say that based on the various COS% of the different wells, the predrill prediction would be to have a 69% Probability of at least one success by the end of the six wells campaign. It is to be noted that the converse of this, the Probability of back to back failure is 31%. None of this guarantees any success but gives an idea of what to expect out of this campaign. With this knowledge, many are better equipped mentally to face the actual outcomes of a campaign rather than have vague or no ideas of this reality. It might be obvious but worth stating that the individual COS' of the wells do not increase, or for that matter change in this curve with each well drilled, but it is the collective probability of success that increases, brought about by drilling up to a certain number of wells. It is to be noted that dependencies between well outcomes can be accounted for but is beyond the scope of the current paper.

Line of Sight Exploration

To illustrate the concept of Line of Sight Exploration, shown in the table in Figure 3 are the movements in COS prior to and post G&G effort. For the sake of simplicity, again, COS is calculated based on three broad parameters, Source, Reservoir, and Trap. Though the numbers are fictitious, the tabulation is actually from the author's worksheets where these factors are tabulated from the start of a project which could begin at the data room stage, then progressing right through prospect stage. For each prospect, some of the key uncertainties are noted and based on experience, a guesstimate is made as to how each parameter could change with proposed work whether it is acquisition of new seismic data, reprocessing seismic data, petrophysical analysis, source studies etc. For illustration purposes, two end members are provided where all G&G work leads to positive COS movements and the case where all G&G effort leads to negative COS movements. A more realistic scenario is where some prospects have positive COS movements and others have negative COS movements. This example is also plotted in Figure 3.

Plotting these likely scenarios ahead of time has several useful functions. Firstly, it forces the G&G team to start the COS estimation process early regardless of knowledge and data availability levels. Then, it encourages the team to work out what data and work is needed to understand the risking of the prospect better. This is a dynamic process right through the G&G effort where movements will happen at various stages of the work effort. In this example, the pre-G&G effort delivers only about 70% Probability of at least one success drilling 6 wells. In the all positive COS movement case, it moves to 90% Probability of at least one success. In the all negative movements of COS case this probability is reduced to around 58%. It is hoped that with these scenarios worked out, the team/ management can decide which prospects they would like to keep/ drill/ exit from etc. at each stage of the process. This is the Line of Sight one keeps from the start to the end point of the game.

‘Velocity’ of Increase in Success Expectations

As geoscientists and engineers, technical specialists including the author recognize our professional tendency to work the problem at hand as hard as is possible. This is indeed laudable and should be always held as an ideal. However, given time, data, technology, expertise constraints at any given point in time, practical decisions need to be made under non-ideal circumstances. At any point in time, given all these constraints, we reach 'irreducible risk' under those circumstances. The graph and table (Figure 4) show a fictitious example of how increasing technical effort can increase the probability of success. The difference between the cases is an increase of 10% COS in each prospect going from Case 1 to Case 4. It is noteworthy that the greatest benefit gained in obtaining 90% probability of at least one success is between the lowest COS Case 1 to next 10% COS higher Case 2. The bring forward of the occurrence of 90% probability of at least one success is greater than 4 wells going from Case 1 to Case 2, ~ 2 wells going from Case 2 to Case 3 and ~1 well going from Case 3 to Case 4.

Defining GCOS and ECOS

Though many explorers may share a common view generally about what they might mean in defining Geological Chance of Success (GCOS) and Economic Chance of Success (ECOS), there can be noteworthy differences in the way it is actually defined. The author's definition of GCOS is the probability that the G&G model as embodied in the hydrocarbon distribution curve as derived from the input parameters represented by the lower left curve is correct (Figure 5). This curve can be equivalently represented by the exceedance probability curve to the right. Thus, the GCOS is the probability that this exceedance probability curve is correct at all points of total recoverable hydrocarbon volumes on the X-axis. The ECOS is thus the product of the probability that the hydrocarbon distribution curve is correct, i.e. GCOS = X% and the probability of occurrence of a hydrocarbon volume that equals or exceeds the Minimum Economic Pool Size (MEPS), Y%. The determination of the MEPS is a subject in its own right involving production profiles, infrastructure, development options, economics, etc.

It is to be noted that the author's method of defining GCOS and ECOS differs from that of Exxon in their 2017 AAPG paper (Rudolph and Goulding, 2017). However, as Exxon has shown, as long as it is internally consistent within their own organization, it can produce impressive results as illustrated below. The author does not claim to have the only right answers to this.

Benchmarks for Exploration Performance

The graphs shown in Figure 6 provide valuable insights into the long-term exploration performance of a great explorer, Exxon. Though there are differences between pre and post drill outcomes, these are within statistically very acceptable ranges in an industry where predictions can differ significantly from outcomes. Embedded in this stellar performance is the rigorous application of science, technology, and a culture of peer reviews that provide stability to predictions over time. No one should be deluded into believing that such performance can be easily emulated. Though Exxon’s exemplary standards are shared in this paper, many companies do not drill even a fraction of the greater than 500 wells drilled by Exxon over 20 years. Understanding the economic performance of a limited trials campaign is quite different from a campaign with a statistically large number of trials.

Companies with lesser financial capability can only drill fewer wells. They will need to prove their technical capacity to make rigorous predictions 'true to their knowledge/ ignorance' over several campaigns before their credentials are established. The thrust of this paper is to enable smaller companies to build up this expertise by building a statistical prediction model that they can check against in each of their 'limited trials' exploration campaigns. Each time a portfolio of wells is drilled without achieving a success though predictions show that 90% probability of success of at least one success is indicated, should lead to reassessment of specific assumptions in the prediction models. In this way, over several exploration campaigns, the team's prediction capabilities can be enhanced.

The study illustrated in Figure 7 shows the exploration results from 2012-2018 for Westwood Global Energy's benchmark group of 36 companies (W36). Westwood risk exploration wells based on analogous play statistics, assigning a pre-drill chance of commercial success (CoCS) based on historic exploration results within a play rather than assessing each individual element. In the study, Westwood risked 892 exploration wells drilled by the W36 group in 2012-2018. The overall technical success rate (TSR) from the wells is 49% and the overall commercial success rate (CSR) is 28%. Covering a different time period, this CSR is 7% lower than Exxon's ECOS ~ 35%. Westwood also assigns a pre-drill volume estimate, based on company guidance (where available) and analogue discovery sizes. It can be seen on the right-hand side that predicted oil volumes are roughly in-line with expectations (overestimating by ~10%), however, predicted gas volumes are widely underestimated by ~90%. This is partly due to a handful of very large gas discoveries – such as Tortue offshore MSGBC, which pre-drill was an oil prospect risked at only 10% CoCS. WGEG's global cross company study provides a useful comparison with Exxon's company specific performance and shows that ~ 30-35% ECOS is an economic reference point for companies to work with, the idea being to equal or better than this figure (Figure 7).

Actual Application of these Ideas in a Limited Trials Exploration Campaign

Provided in Figure 8 is a real example with numbers actually calculated prior to a certain company's exploration campaign. The prospect COS (actually the GCOS), NPV, and Capex were as computed at that time but the ECOS was not a focus in this campaign. The author has used an average ratio of GCOS/ ECOS based on the Exxon and WGEG average numbers and hence multiplied GCOS by 0.65 to obtain ECOS for all prospects. Technically, each prospect GCOS/ ECOS will look different but this approximation is intended for illustration purposes only. The 90% probability of at least one GCOS occurs at just after the 3rd well and the 90% probability of at least one ECOS occurs at the just before the 6th well. The red curve shows the NPV of a given prospect less the Capex of the total exploration drilling campaign. This is to illustrate what happens when a given well is the only well successful in the whole campaign and having to carry the Capex of the total campaign. This is aligned with real life experience where what matters most is the first success after which the world changes yet again. This curve shows that when the 90% probability of at least one GCOS occurs with the 3rd well, with the 3rd well the only success, the net value of the exploration campaign would be close to zero. Similarly, the 90% probability of at least one ECOS occurs just about the 6th well which puts the NPV into a significant -$60 million dollars, assuming the 6th well is the only success in the campaign and being the one carrying the whole cost of the campaign. It is to be noted that these wait times for success are not unusual in exploration campaigns. The green curve is just the cumulative Capex of the program.

A simple exercise like this one can immediately raise red flags that one should pay attention to, especially with the real possibility that there is a strong probability of this planned campaign heading for a negative economic outcome.

Conclusions

This paper provides a 'Line of Sight' between the first set of evaluations of exploration prospects right through to how probabilities change with more additional work, eventually leading to drilling and real economic outcomes. Working out GCOS and ECOS rigorously pre-drill, companies can get a good idea about the probability of whether a campaign can end up with an economic benefit. If all stakeholders are informed along the whole process, there is less chance of disruptions to ongoing campaigns which arise purely out of not understanding the underlying statistics of limited trials exploration campaigns.

Appreciation

The author would like to thank the several referees who reviewed this paper and provided valuable feedback that hopefully makes the ideas presented here clearer. I am very grateful for their thoughtfulness, time, and effort. And very importantly, I would also like to thank my wife and two children for putting up with me during the long hours I have been preoccupied with formulating and writing these thoughts over the years.

Note: 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.

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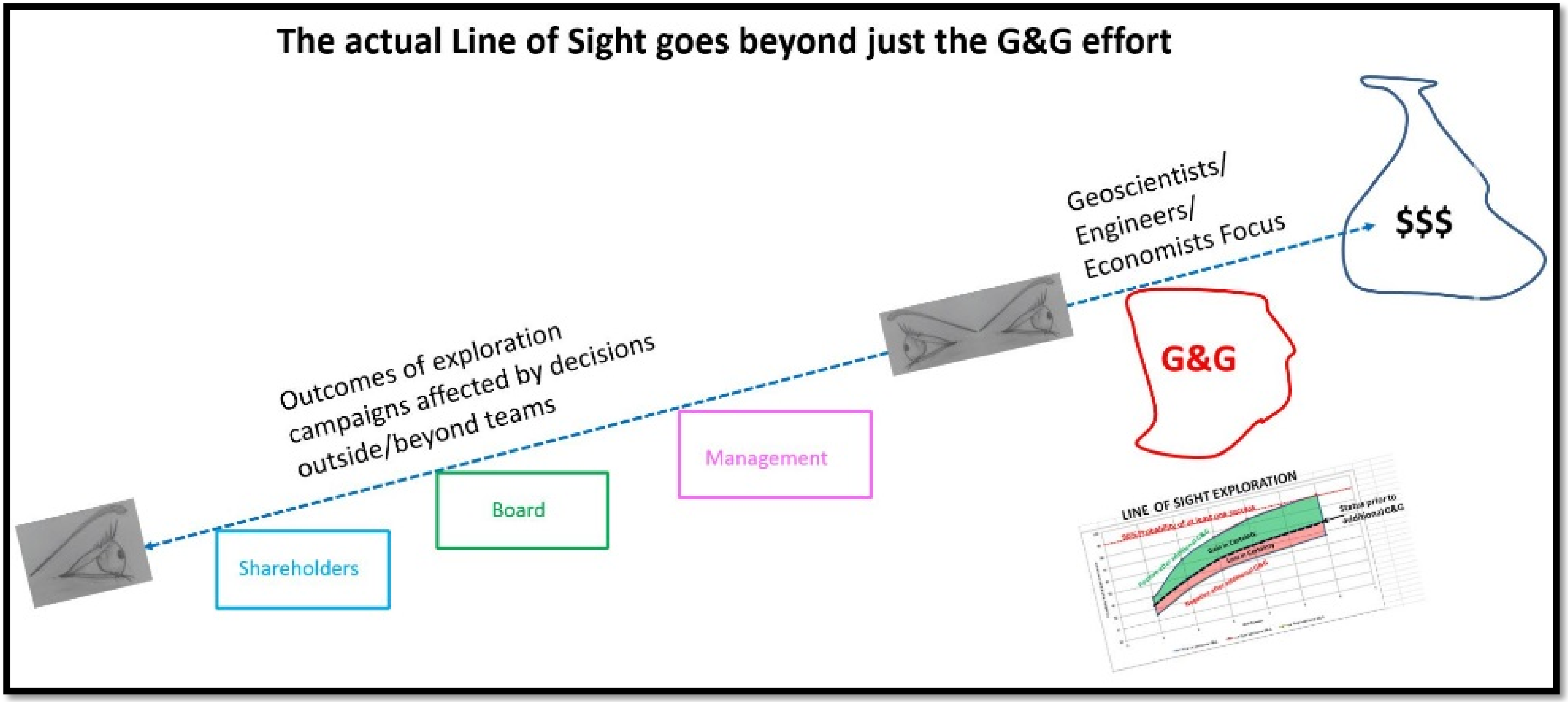
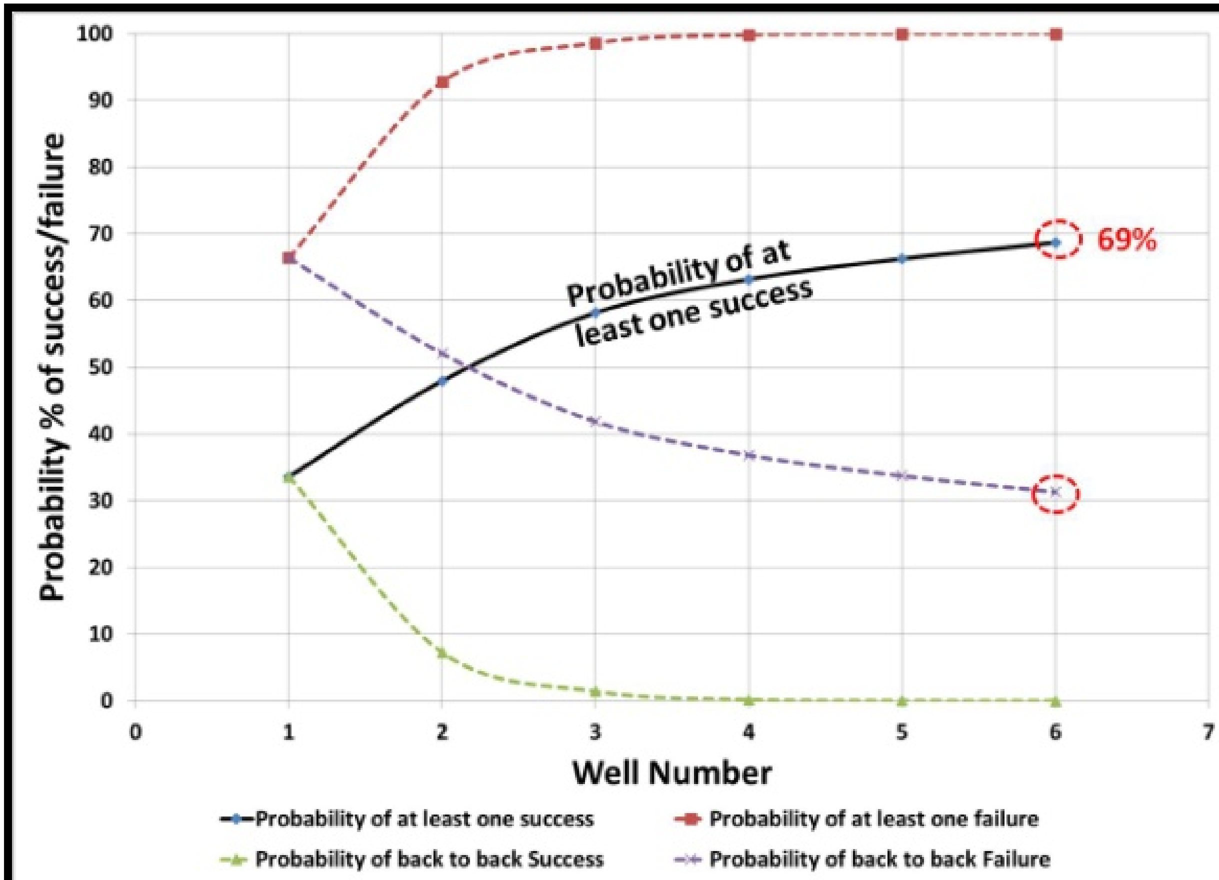


Figure 1. The Line of Sight Concept.

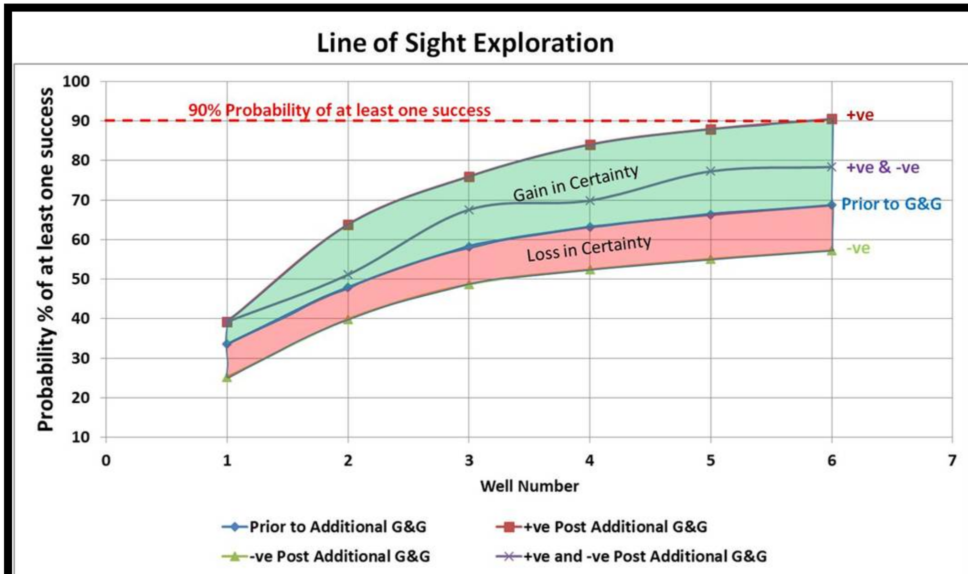


Prospects		Source	Reservoir	Trap	COS%
1		0.7	0.6	0.8	34
2		0.8	0.3	0.9	22
3		0.7	0.4	0.7	20
4		0.6	0.5	0.4	12
5		0.7	0.4	0.3	8
6		0.6	0.4	0.3	7

Calculation: E.g. At the 6th well, Probability of back to back failure = (1-0.34)x(1-0.22)x(1-0.20)x(1-0.12)x(1-0.08)x(1-0.07) = 31%
Thus, Probability of at least one success is 69%

Which curve is the 'right' measure for expectations?

Figure 2. Which is the 'right' curve to convey expectations of a drilling campaign?



Movements in COS - prior to and post G&G

Company X Leads and Prospect prior to additional work

	Prospects	Source	Reservoir	Trap	COS%	Key uncertainty	Proposed additional G&G
		COS calculation					
1	A	0.7	0.6	0.8	34	Areal extent of trap	Seismic Repro/ New Seismic/Petrophysics
2	B	0.8	0.3	0.9	22	Reservoir quality	Core/ frac studies/ seismic repro/ Petrophysics
3	C	0.7	0.4	0.7	20	Reservoir quality	Seismic Repro/ New Seismic/Petrophysics
4	D	0.6	0.5	0.4	12	Trap definition	New Seismic, Seismic Repro, Petrophysics
5	E	0.7	0.4	0.3	8	Trap definition	New Seismic, Seismic Repro, Petrophysics
6	F	0.6	0.4	0.3	7	Trap definition	New Seismic, Seismic Repro, Petrophysics

Positive COS Movements

Company X Leads and Prospect post additional work

		Source	Reservoir	Trap	COS%
1	A	0.7	0.7	0.8	39
2	B	0.9	0.5	0.9	41
3	C	0.7	0.6	0.8	34
4	D	0.8	0.6	0.7	34
5	E	0.7	0.5	0.7	25
6	F	0.7	0.5	0.6	21

Negative COS Movements

Company X Leads and Prospect post additional work

		Source	Reservoir	Trap	COS%
1	A	0.7	0.6	0.6	25
2	B	0.7	0.4	0.7	20
3	C	0.7	0.3	0.7	15
4	D	0.6	0.3	0.4	7
5	E	0.7	0.4	0.2	6
6	F	0.6	0.4	0.2	5

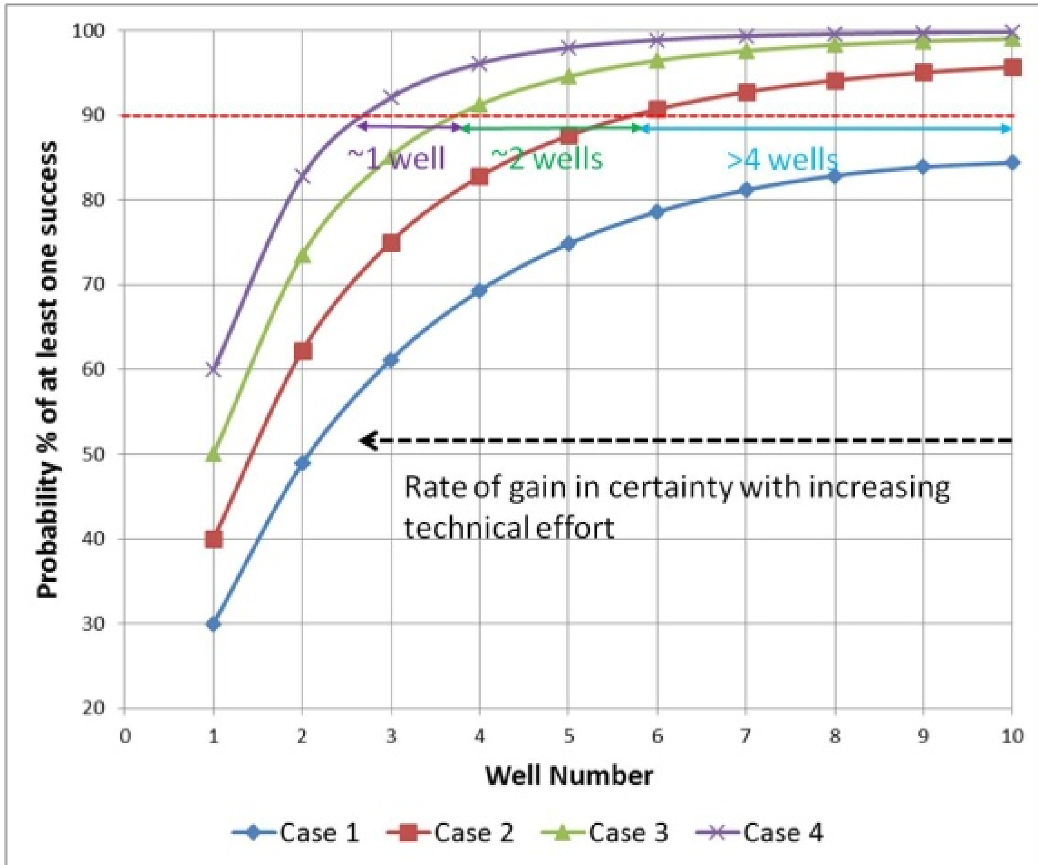
Positive and Negative COS Movements

Company X Leads and Prospect post additional work

		Source	Reservoir	Trap	COS%
1	A	0.7	0.7	0.8	39
2	B	0.7	0.4	0.7	20
3	C	0.7	0.6	0.8	34
4	D	0.6	0.3	0.4	7
5	E	0.7	0.5	0.7	25
6	F	0.6	0.4	0.2	5

Figure 3. Prior to Post G&G COS Movements - Line of Sight Exploration. Drill/ hold/ modify/ exit decisions.

***'Velocity'* of 90% probability expectations with increased technical effort**



COS% for different cases

Case 1	Case 2	Case 3	Case 4
30	40	50	60
27	37	47	57
24	34	44	54
21	31	41	51
18	28	38	48
15	25	35	45
12	22	32	42
9	19	29	39
6	16	26	36
3	13	23	33

Increase in technical effort

Need reality check in real life situations when ***good enough is good enough***, for particular given circumstances

Figure 4. The *'Velocity'* of expectation increase with increased technical effort diminishes going from the lowest to highest COS case. A fact to be kept in mind when making decisions under 'imperfect' conditions.

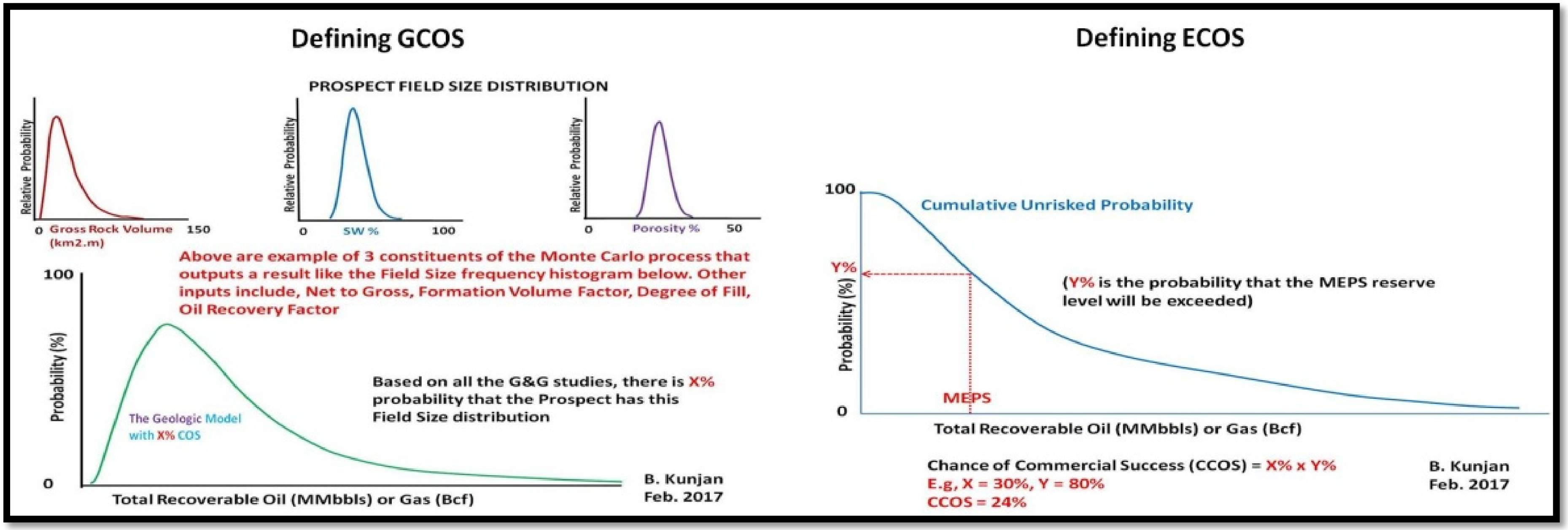


Figure 5. Defining GCOS and ECOS.

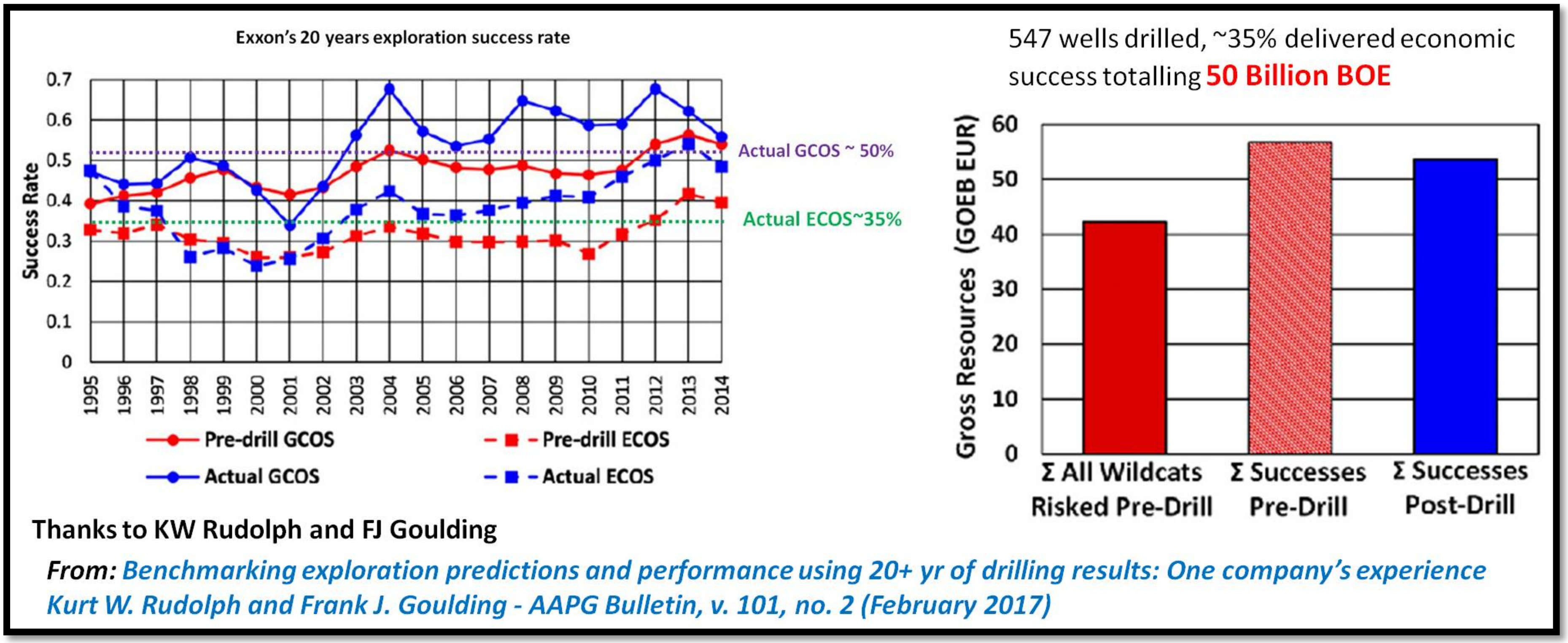


Figure 6. Exxon's GCOS, ECOS and hydrocarbon discovery volumes pre and post drill over 20 years (1995 to 2014) is very impressive. At an average ECOS of around 35%, the 547 wells Exxon participated in accreted ~50 Billion BOE.

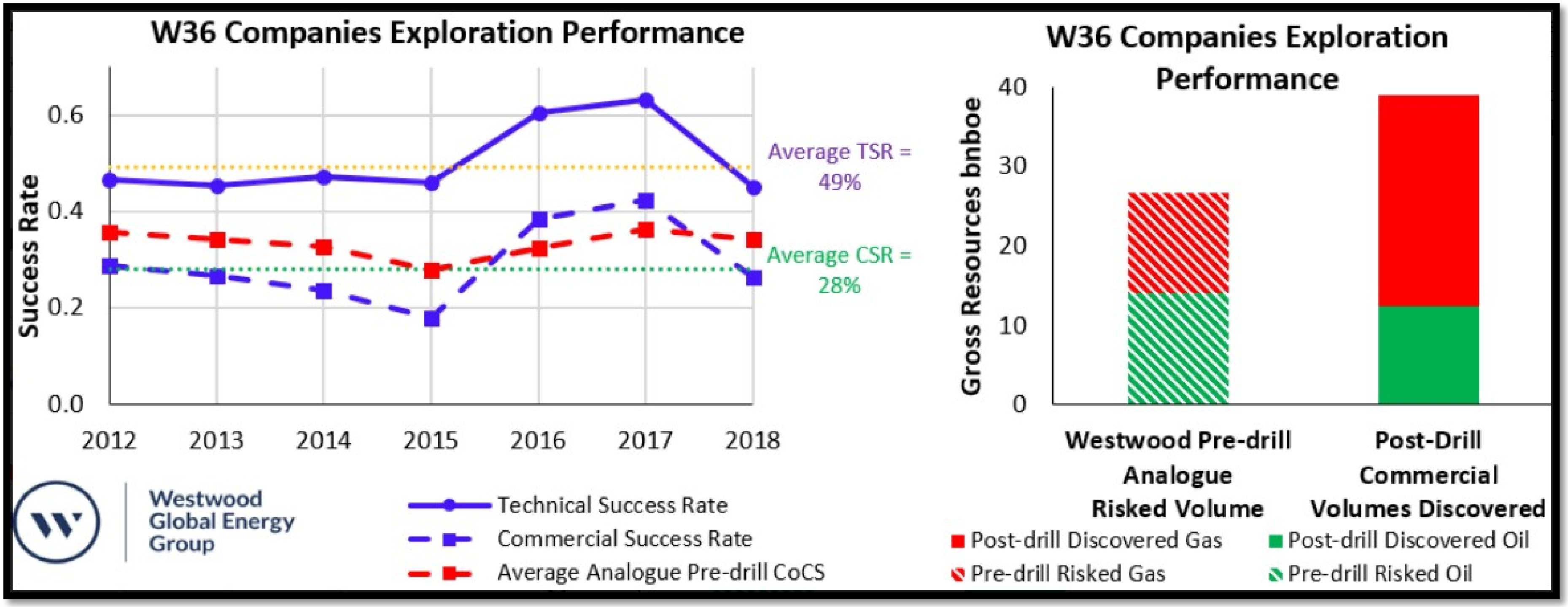
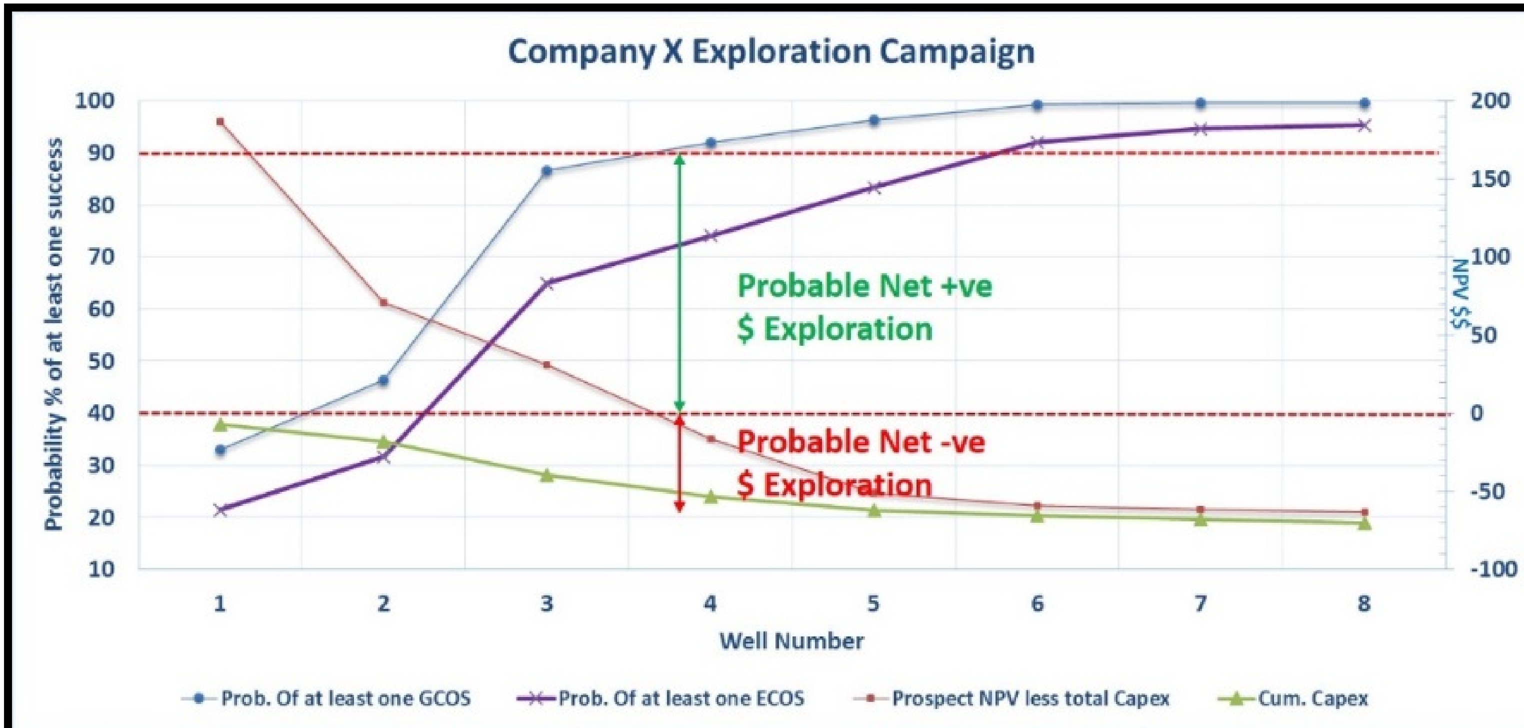


Figure 7. Thanks to WGEG for sharing their updated analysis of global exploration results which shows a Global drilling performance of Average TSR (GCOS) = 49% and Average CoCS (ECOS) = 28%.



90% GCOS achieved after 3 wells

- when at ~ zero $$ territory

90% ECOS achieved only at ~ 6th well

- when in –ve $$ territory

Prospect	COS %	ECOS %	Net Company NPV A$m	Company Capex A$m	Prospect NPV less total other Capex A$m
1	33	21	250	7	187
2	20	13	130	12	71
3	75	49	80	21	31
4	40	26	40	14	-17
5	55	36	10	9	-51
6	80	52	8	3	-59
7	50	33	6	3	-62
8	20	13	5	2	-63
	Total		529	70	

Figure 8. A real example of how probability of success predictions can be analyzed ahead of the drill to show the probability of an economic outcome.