# Economic Risk and Decision Analysis for Oil and Gas Industry
## CE81.9008

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Presented by
Dr. Thitisak Boonpramote

Department of Mining and Petroleum Engineering, Chulalongkorn University

# Decision Analysis
## Recognizing a "Value of Information" situation

## Decision making under uncertainty

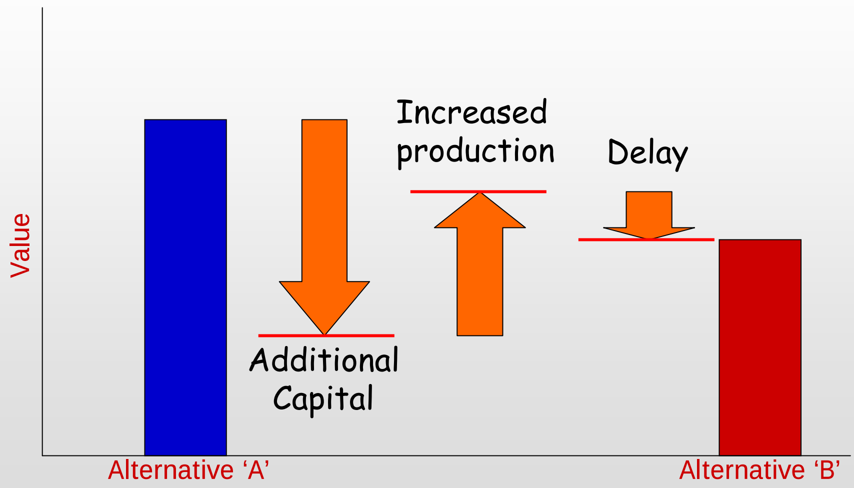
•Nearly all important decisions, business or personal, are made under conditions of **uncertainty**.

•We lack **information** about factors that could **significantly affect the outcomes** of our decisions.

•The decision maker must choose one course of action from all that are available.

•The difficulty is in understanding the consequences or outcomes of the different courses of action.

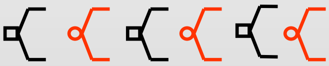
## Understanding the differences between alternatives (value drivers)



## Two general patterns with regards to decision-making

A general EMV pattern, where the decisions occur up front and then all the uncertainties occur after those decisions are made.

A phased decision pattern, where the decisions are interspersed with the uncertainties.



A phased decision pattern is indicative of a **"Value of Information"** situation

## Value of information *general principles*

- There must be a **decision which can change** as a result of the information
- Confidence has no intrinsic value. Value is added by making better, higher EMV decisions
- The **state of the world** can not change w/out new information
- **Value of information** is the difference between the project with the information and the project without information

## Value of Information

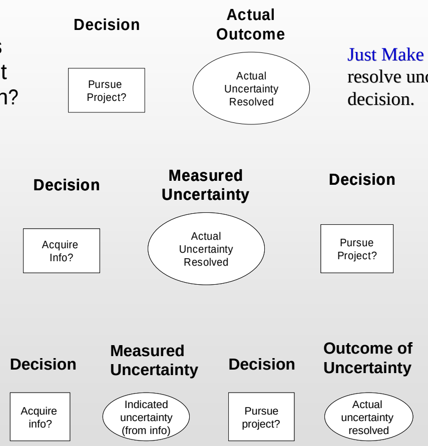
- **New** or **additional information** can **reduce uncertainty**
- **Reduced uncertainty** should increase payoff and reduce variance
- Additional information costs money
- Examples
  - Seismic survey
  - Laboratory analysis
  - Services of consultant
  - Market survey before launching new project

## Questions to be Answered Before Buying Additional Information

- Is the additional information worth the cost?
- If several potential sources of information exist, which one if preferred?

## Perfect / Imperfect information

**The baseline**, what is the value of the project without the information?




Just Make the Decision – no effort to resolve uncertainty before making the decision.

**Phased decision patterns:**

**Perfect information**

**Imperfect information**

**Perfect information** -- **completely resolve uncertainty** before making the decision.

**Imperfect information** – **cannot completely resolve uncertainty**. The prediction may be wrong, uncertainty remains.

## Calculating the value of information

- Value of information is the **difference** between the project **with the information** and the project **without information**
- The value of both perfect and imperfect information can be calculated.

| Specific Scenario | EMV |
|---|---|
| A) Value of the project without information | $MM |
| B) Value of the project - Perfect Information | $MM (B>A) |
| C) Value of the project - Imperfect Information | $MM (C>A, C<B) |

## Expected Value of Perfect Information (EVPI)

## Expected Value of Perfect Information

- **Expected value of perfect information (EVPI)** is **expected payoff with perfect information (EPPI)** minus **expected payoff without information**
- EVPI is amount we can spend on acquiring perfect information
- EVPI gives **upper-bound** for imperfect information, since perfect information is **rarely available**

## Expected Value of Perfect Information

- Best payoff (from perfect information) found by first determining **maximum payoff** of each event, then multiplying each maximum by probability of event
- EVPI then calculated as **difference** between **best payoff** and **most likely payoff**
- Process illustrated by example

## Example: Expected Value of Perfect Information

- For decision problem discussed earlier (leasing 60 acres to join drilling unit and determining whether to drill, farm out, or back in)
  - Geologists believe **additional seismic data** will significantly reduce uncertainty – can tell us "dry hole" or "producer," but not size of reserve
  - We want to determine **maximum amount** we can pay for additional seismic

## Example: Expected Value of Perfect Information

| Outcomes | Probability | Net Present Value, M$ | | |
|---|---|---|---|---|
| | | Drill with 37.5% WI | Farm out Retain ORI | 37.5% Back-in |
| Dry hole | 0.25 | -30 | 0 | 0 |
| 20 MSTB | 0.30 | 4.357 | 8.733 | 0.750 |
| 35 MSTB | 0.25 | 45.448 | 14.646 | 34.142 |
| 50 MSTB | 0.15 | 87.411 | 20.693 | 73.712 |
| 65 MSTB | 0.05 | 125.863 | 26.401 | 111.141 |

## Example: Expected Value of Perfect Information

- Choose **maximum value** in each row of given data to represent NPV of perfect information
  - Since information perfect, **dry hole risk** has vanished

## Example: Expected Value of Perfect Information

| Outcomes | Probability | Net Present Value, M$ | | |
|---|---|---|---|---|
| | | Drill with 37.5% WI | Farm out Retain ORI | 37.5% Back-in |
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## Example: Expected Value of Perfect Information

- Multiply NPV values assuming perfect information by probabilities to obtain at components of expected value
- Add components of expected value to determine **expected payoff of perfect information (EPPI)**
- Subtract **EMV under uncertainty** (which was $25.375 M for back-in option) from EPPI to determine EVPI

## Example: Expected Value of Perfect Information

| Outcomes | Probability | Perfect Information | |
|---|---|---|---|
| | | NPV, M$ | EPPI, M$ |
| Dry hole | 0.25 | 0 | 0 |
| 20 MSTB | 0.30 | 8.773 | 2.620 |
| 35 MSTB | 0.25 | 45.448 | 11.362 |
| 50 MSTB | 0.15 | 87.411 | 13.112 |
| 65 MSTB | 0.05 | 125.863 | 6.293 |
| | 1.00 | | 33.387 |

## Example: Expected Value of Perfect Information

EVPI = EPPI – EMV

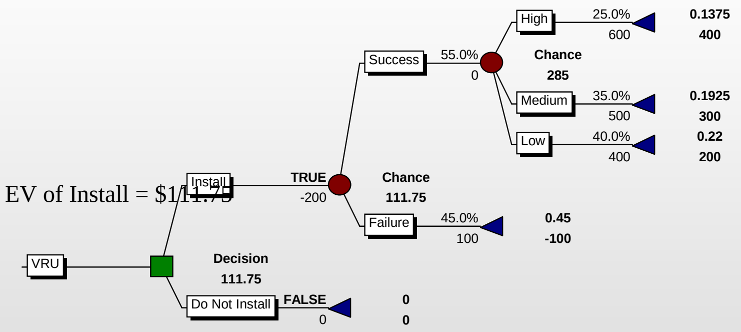
= $33.387 M – $25.375 M

= $8.012 M

We can afford to pay no more than $8.012 M for seismic

## VRU Installation Revisited

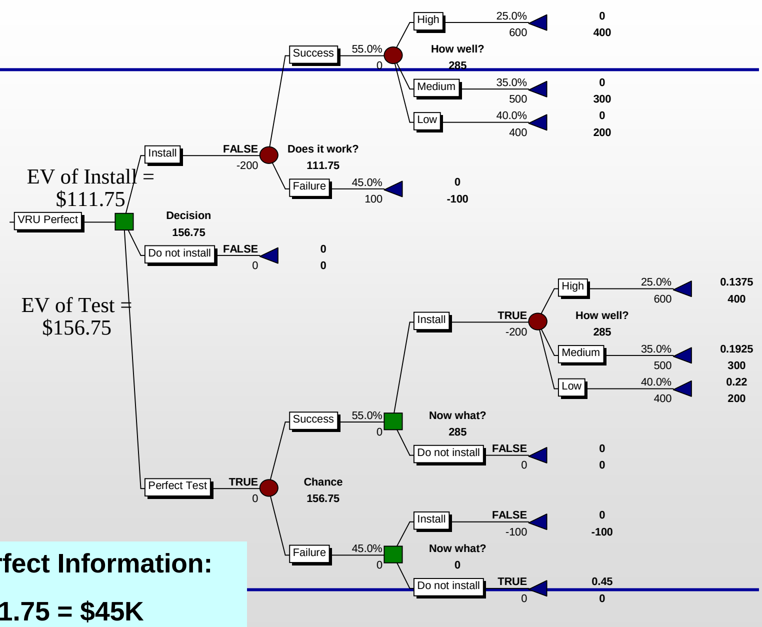
Recall the analysis of the vapor recovery unit installation




Suppose that we could perform a **perfect test for $20,000** that would determine whether the project would be successful with 100% reliability.

**What would this test be worth?**

## Decision tree with obtain perfect information branch




**Value of Perfect Information:**

**$156.75-$111.75 = $45K**

## Some Comments on EVPI

- In determining the EVPI, **no information costs are included** on the diagram.
- After rolling back the tree, the **difference** between the **information alternative** and the **best alternative without information** is directly available.
- Perfect information about a given event means complete elimination of uncertainty about the event's outcomes; after receiving the information, you will know exactly which outcome will occur.
- The decision to obtain perfect information **does not eliminate uncertainty**. Until the information is received, you are still uncertain about what the information will reveal. Value of information is from an a priori perspective.

# Expected Value of Imperfect Information (EVII)

## Why worry about imperfect information?

- The **value of perfect information** can be calculated, but actually acquiring this type of information is rare.
- **Imperfect information** must be risked. Must take into account the possibility of an untrue (inaccurate) prediction.
- The magnitude of the difference between **the value of perfect** and **imperfect information** relates to the **risk of untrue predictions** from imperfect information.
- Failure to take into account the impact of imperfect information can result in incorrect estimations of value.

## History lesson

Bayes' Theorem

A statistical method to revise probability estimates from new information.

*"a method by which we might judge concerning the probability that an event has to happen, in given circumstances, upon supposition that we know nothing concerning it but that, under the same circumstances, it has happened a certain number of times, and failed a certain other number of times."*

## Bayes' Theorem or Rule

- Used to **revise probability of an earlier event** given later event
- Used when solving problems concerning **value of additional information** that will result in revised probabilities

## Bayes' Theorem

Three types of probabilities we need to be concerned with:

*Prior probabilities* **-** the probabilities established for **some actual event *before*** we gather **additional information**

*Conditional probabilities* **-** the probabilities predicted by **some test** if an actual event really happens

*Posterior probabilities* - the probabilities of the **outcome of an actual event** (with some prior probability) ***following a test*** with known conditional probability

## Bayesian Analysis

Prior Probability + Likelihood + Application of Bayes Th. → Posterior Probability

- **Prior Distribution**: probability distribution assessed for the random variable of interest before obtaining the empirical data.
- **Likelihoods**: **Conditional probabilities** where the probability of a given observation is conditioned on the event of interest.
- **Posterior Distribution**: **revised probability** distribution for the random variable of interest after obtaining the empirical data (also **conditional probabilities**).

## "Bayes' Theorem" the basics

$$P(Ei \mid B) = \frac{P(B \mid Ei) * P(Ei)}{\sum_{i=1}^{n} \left[ P(B \mid Ei) * P(Ei) \right]}$$

The probability of Ei given the outcome of event B

*(posterior probability)*

## Bayesian Analysis

$$P(E|R) = \frac{P(E)\,P(R|E)}{P(E)\,P(R|E) \;+\; P(E')\,P(R|E')}$$

- *Note that*
  - **P(E)** is unconditional probability of an event called **Priori probability**.
  - P(R|E) is conditional (**likelihood**) of ***a symptom*** (or ***new knowledge***) **given the event**
  - P(E|R) is conditional (**posterior**) probability of an **event given the new knowledge**
  - P(E)*P(R|E) is **joint probability** of a **symptom and event**
  - Summation of the joint probability for any event is a **marginal probability**
  - Applying the multiplication rule we can derive. . .

$$P(E|R) = \frac{P(E \text{ and } R)}{P(R)}$$

## Bayes' Theorem or Rule

Posterior probabilities

Prior or source probabilities

$$P(A_i|B) = \frac{P(B|A_i)\times P(A_i)}{\sum_{i=1}^{k} P(B|A_i)\times P(A_i)}$$

Product of branch probabilities leading to B through A

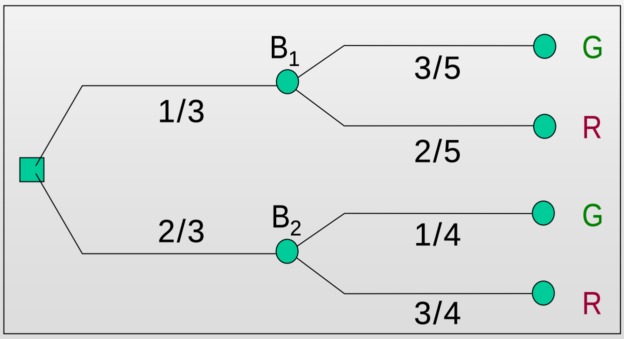
Sum of all branch probabilities leading to B

## Probability of Drawing Pencils

- First box contains 3 green, 2 red pencils
- Second box contains 1 green, 3 red
- One die is rolled
  - 1 or 2 → draw from first box
  - 3 to 6 → draw from second box
- Pencil drawn is green
- Calculate probability of drawing from each box

## Probability of Drawing Pencils

- First box contains 3 green, 2 red pencils
- Second box contains 1 green, 3 red



## Probability of Drawing Pencils

- First box contains 3 green, 2 red pencils
- Second box contains 1 green, 3 red

$$P(A \cup B) = P(A) + P(B) = \frac{1}{6} + \frac{1}{6} = \frac{1}{3}$$

Box 1

$$P(B_1) = \frac{1}{3}$$

$$P(G) = \frac{3}{5}$$

$$P(R) = \frac{2}{5}$$

Box 2

$$P(B_2) = 1 - \frac{1}{3} = \frac{2}{3}$$

$$P(G) = \frac{1}{4}$$

$$P(R) = \frac{3}{4}$$

## Probability of Drawing Pencils

- First box contains 3 green, 2 red pencils
- Second box contains 1 green, 3 red

$$P(B_1|G) = \frac{P(G|B_1) \times P(B_1)}{\sum_{i=1}^{2} P(G|B_i) \times P(B_i)} = \frac{\left(\frac{3}{5}\right)\left(\frac{1}{3}\right)}{\left(\frac{3}{5}\right)\left(\frac{1}{3}\right) + \left(\frac{1}{4}\right)\left(\frac{2}{3}\right)}$$

$$= \frac{6}{11} = 0.5455 \text{ or } 54.55\%$$

$$P(B_2|G) = 1 - 0.5455 = 0.4545 \text{ or } 45.45\%$$

## Using Probability Tree Format

- Construct tree with branches representing all possible events; write prior probabilities on branches
- Attach new branches to represent new information obtained (or to be obtained)
- Multiply prior probabilities by conditional probabilities
- Sum joint probabilities
- Divide each joint probability by sum of joint probabilities to obtain posterior probabilities

## Using Table Format

| Event<br>1 | Prior Prob.<br>2 | Conditional Probability<br>3 | Joint Probability<br>4 = (2 × 3) | Posterior Probability<br>5 = 4/Σ(4) |
|---|---|---|---|---|
| A | P(A) | P(X/A) | P(A) × P(X/A) | P(A) × P(X/A)/Σ(4) |
| B | P(B) | P(X/B) | P(B) × P(X/B) | P(B) × P(X/B)/Σ(4) |
| …. | … | … | … | … |
| N | P(N) | P(X/N) | P(N) × P(X/N) | P(N) × P(X/N)/Σ(4) |
| | Σ(2) = 1.0 | | Σ(4) | Σ(5) = 1.0 |

## Using Table Format

- Input all possible events in Column 1
- Assess prior probability of each event and input in Column 2; total must equal 1.0
- Input likelihood probabilities into Column 3
- Calculate joint probabilities by multiplying Columns 1 and 3; sum in Column 4
- Divide each joint probability by sum of joint probabilities to obtain posterior probabilities

## Expected Value of Imperfect Information

- **Imperfect information** changes degree and nature of uncertainty without eliminating it
- Example from seismic
  - Perfect information would be 100% reliable
  - Actual expectations might be 90% probability that seismic will indicate structure when structure is present, and 10% probability that seismic will indicate structure when structure is not present

## Expected Value of Imperfect Information

- **Expected value of imperfect information (EVII)** is **expected payoff with imperfect information** minus expected payoff without information
- **Expected net gain (ENG)** is expected value of information (perfect or imperfect) less **cost of obtaining information**

## Expected Value of Imperfect Information

- **Bayesian methodology** used to **revise prior probabilities** and **determine new posterior probabilities**, calculated using new information available through experiments or tests
- **Substitute posterior probabilities** in place of **prior probabilities** in outcome state
- Expected payoff thus calculated taking into account posterior probabilities in place of prior probabilities

## Implementing Bayesian Analysis

- Determine course of action that would be chosen using only prior probabilities and record EMV of this course of action
- Identify possible insights **new information** can provide
- Assign **probabilities to new information (conditional probabilities)**

## Implementing Bayesian Analysis

- Calculate **joint probabilities** (product of prior probabilities and conditional probabilities)
- Calculate **marginal probabilities** (sum of appropriate joint probabilities)
- Calculate **posterior probabilities** (joint probabilities divided by marginal probabilities)
- Replace **initial (prior) probabilities** by **revised (posterior) probabilities** and calculate revised (less uncertain) EMV of project

## Imperfect Information and the VRU

- Consider our **VRU installation decision problem** and instead of a perfect test, suppose we could spend **$10,000** on a test that would produce “Good” or “Bad” results.
- We also know that
  - **if the VRU will be successful**, then the probability of the **test indicating a “Good”** result is **0.90**.
  - **If the VRU will be a failure**, then the probability of **a “Good”** result is **0.30**.
- **What would this test be worth?**

## Bayesian Revision - Table Format

| Event | Prior | Likelihood | Joint Prob. | Posterior |
|---|---|---|---|---|
| $E_1$ | $P(E_1)$ | $P(R\|E_1)$ | $P(E_1)\,P(R\|E_1)$ | $P(E_1)\,P(R\|E_1) / P(R)$ |
| $E_2$ | $P(E_2)$ | $P(R\|E_2)$ | $P(E_2)\,P(R\|E_2)$ | $P(E_2)\,P(R\|E_2) / P(R)$ |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |
| $E_n$ | $P(E_n)$ | $P(R\|E_n)$ | $P(E_n)\,P(R\|E_n)$ | $P(E_n)\,P(R\|E_n) / P(R)$ |
| | ------------- | | ------------ | ----------------------- |
| | **$\Sigma$ = 1.0** | | **$\Sigma$ = P(R)** | **$\Sigma$ = 1.0** |

*where,*
**E** *denotes the event of interest and*
**R** *denotes the empirical observation*

# Bayesian Revision – VRU Probability

Let **S** denote a **successful VRU operation** and **F** denote a **failure**.

**From priori:** P(S) = 0.55 P(F) = 0.45

Let **G** denote a **"Good" on the test** and **B** denote a **"Bad" reading**.

So, **likelihood**: P(G|S) = 0.90 P(G|F) = 0.30

**Test Result "Good"**

| Event | Prior | Likelihood | Joint Prob. | Posterior |
|---|---|---|---|---|
| S | P(S) = 0.55 | P(G\|S) = 0.90 | P(G,S) = .495 | .P(S\|G) =**0.79** |
| F | P(F) = 0.45 | P(G\|F) = 0.30 | P(G,F) = .135 | .P(F\|G) =**0.21** |
| | ---------------- | | ------------ | ------------------- |
| | **1.0** | | **0.630** | **1.0** |

**Test Result "Bad"**

| Event | Prior | Likelihood | Joint Prob. | Posterior |
|---|---|---|---|---|
| S | P(S) = 0.55 | P(B\|S) = 0.10 | P(B,S) = .055 | .P(S\|B) =**0.15** |
| F | P(F) = 0.45 | P(B\|F) = 0.70 | P(B,F) = .315 | .P(F\|B) =**0.85** |
| | ---------------- | | ------------ | ------------------- |
| | **1.0** | | **0.370** | **1.0** |

# Calculations in a spreadsheet

**Illustration of Bayes' rule using VRU example**

Prior probabilities of success (S) or failure (F)

| | Success | | Failure | |
|---|---|---|---|---|
| | P(S)= | 0.55 | P(F)= | 0.45 |

Liklihoods of test results, given the eventual success or failure status of the well

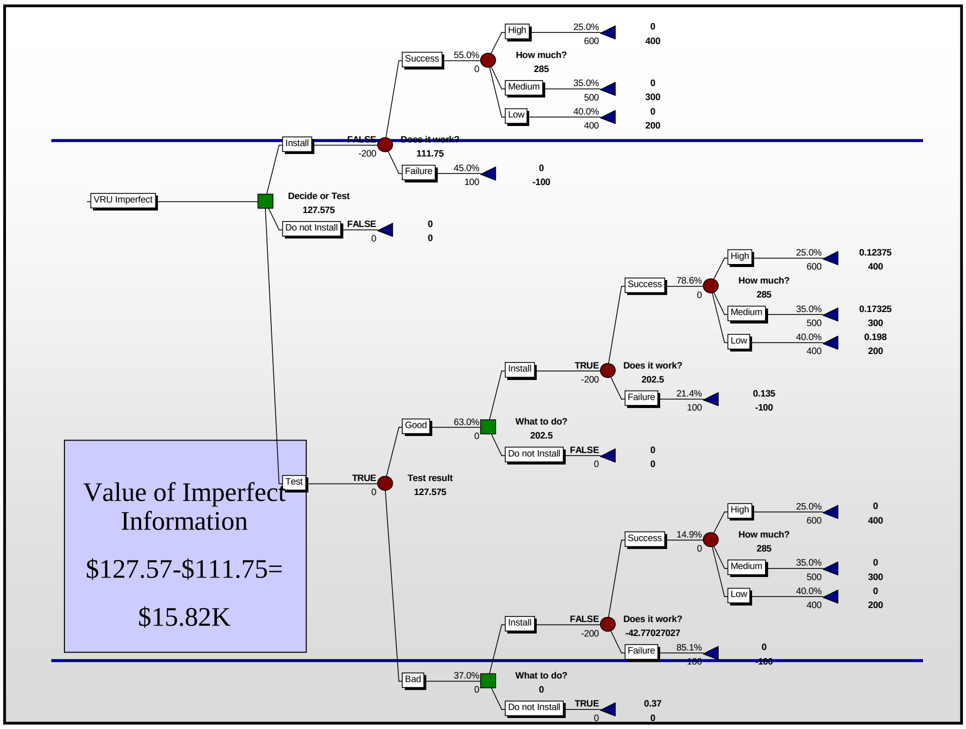
| | Success | | Failure | |
|---|---|---|---|---|
| Test result "Good" | P(G\|S)= | 0.9 | P(G\|F)= | 0.3 |
| Test result "Bad" | P(B\|S)= | 0.1 | P(B\|F)= | 0.7 |
| | Sum= | 1 | | 1 |

Joint probabilities of well status and test results

| | Success | | Failure | | Unconditional | |
|---|---|---|---|---|---|---|
| Test result "Good" | P(G&S)= | 0.495 | P(G&F)= | 0.135 | P(G)= | 0.63 |
| Test result "Bad" | P(B&S)= | 0.055 | P(B&F)= | 0.315 | P(B)= | 0.37 |
| | Sum= | | | | | 1 |

Posterior probabilities of success or failure

| | Success | | Failure | | Sum |
|---|---|---|---|---|---|
| Test result "Good" | P(S\|G)= | 0.79 | P(F\|G)= | 0.21 | 1 |
| Test result "Bad" | P(S\|B)= | 0.15 | P(F\|B)= | 0.85 | 1 |




## More Test on VRU

- Suppose that there is a third test available for only **$5000** that also produces “Good” or “Bad” results
  - If  the VRU will be successful, then the probability of “Good” results is **0.7**
  - If the VRU will be a failure, then the probability of “Good” results is **0.4**.
- **What would this test be worth?**

# Bayesian Revision – VRU Probability

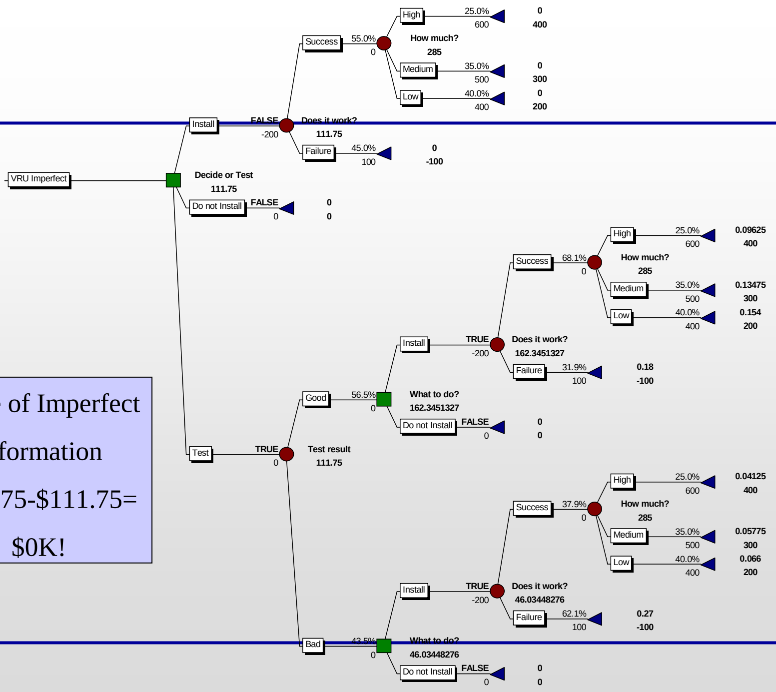
| | | |
|---|---|---|
| **Priori:** | **P(S) = 0.55** | **P(F) = 0.45** |
| **Likelihood:** | **P(G\|S) = 0.70** | **P(G\|F) = 0.40** |

**Test Result "Good"**

| Event | Prior | Likelihood | Joint Prob. | Posterior |
|---|---|---|---|---|
| S | P(S) = 0.55 | P(G\|S) = 0.70 | P(G,S) = .385 | .P(S\|G) =**0.68** |
| F | P(F) = 0.45 | P(G\|F) = 0.40 | P(G,F) = .180 | .P(F\|G) =**0. 32** |
| | ---------------- | | ------------ | ------------------- |
| | **1.0** | | **0.565** | **1.0** |

**Test Result "Bad"**

| Event | Prior | Likelihood | Joint Prob. | Posterior |
|---|---|---|---|---|
| S | P(S) = 0.55 | P(B\|S) = 0.30 | P(B,S) = .165 | .P(S\|B) =**0.38** |
| F | P(F) = 0.45 | P(B\|F) = 0.60 | P(B,F) = .270 | .P(F\|B) =**0.62** |
| | ---------------- | | ------------ | ------------------- |
| | **1.0** | | **0.435** | **1.0** |



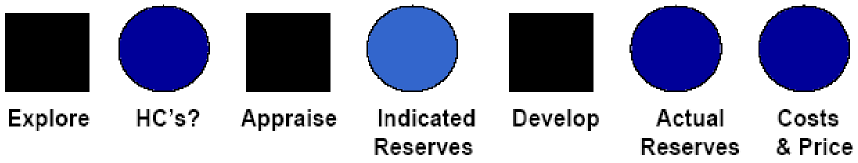

Value of Imperfect Information

$111.75-$111.75=

$0K!

## Value of Information (VoI) Considerations in E&P Business

## VOI: It's place in E&P

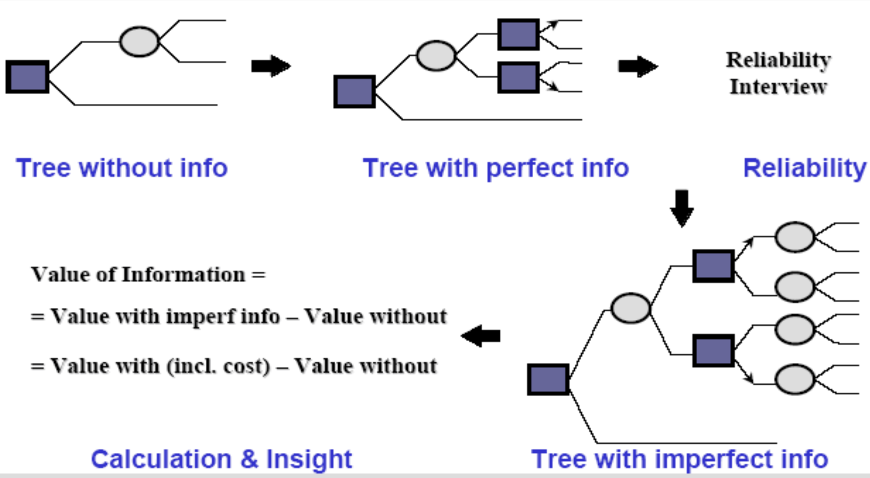



*The entire oil field life cycle is a series of value of information stages.*

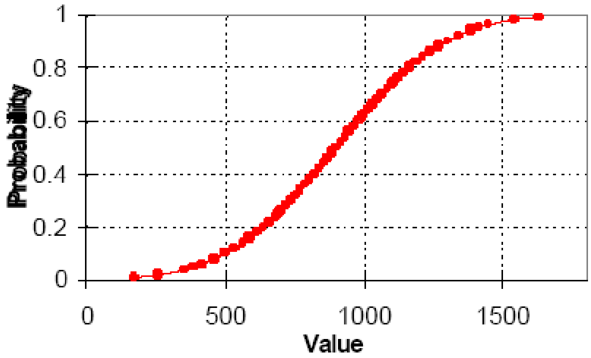
## Three Distinct patterns may be identified

- **Seismic & Drilling**
  - Seismic – 2D, 3D seismic processing
  - Hydrocarbon presence geologic dependencies (well or seismic)
- **Appraisal & Development:**
  - Concept/contract selection

## General VOI Analysis Pattern



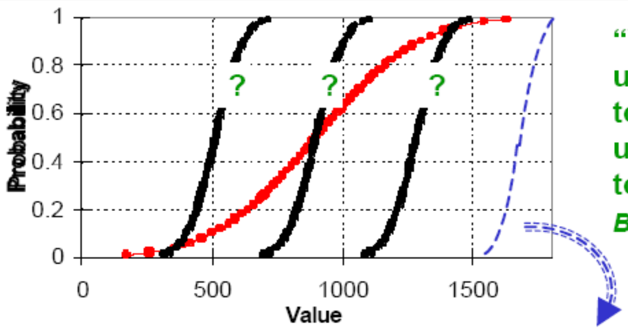
## Never allowing information to change your state of nature.




"Your uncertainty today…."

If the above graph represents your uncertainty range for the particular variable before you gather the information, then...

## Information should narrow your uncertainty and position you within the original distribution, it shouldn't alter the original range.



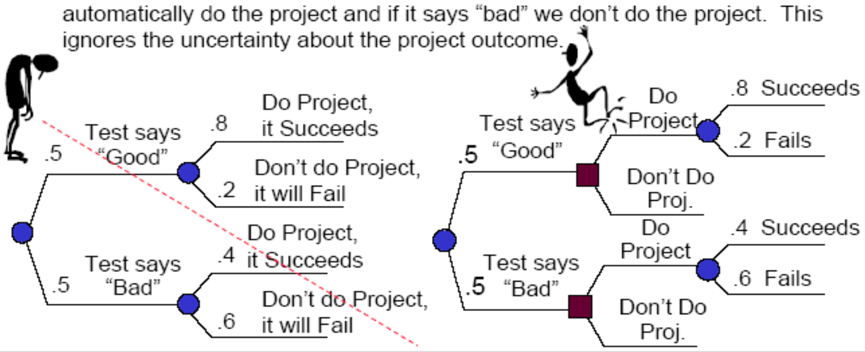

"Your uncertainty today... is your uncertainty today"

*B.C. Cotner*

If with information, your uncertainty range <u>in your model</u> is much higher or lower than originally assessed, then you've made a mistake or you need to adjust the original assessment. Otherwise, you have modeled information influencing the assessed "state of nature" and altering the probabilities.

## Novice teams doing value of information calculations frequently construct the tree incorrectly.

- **Failure to construct the tree with the decision (about whether to do the project) following the test results.** Without the decision, the information can't help you decide what to do about the project.
- A related mistake is drawing the tree so that if the information says "good", we automatically do the project and if it says "bad" we don't do the project. This ignores the uncertainty about the project outcome.




## Never let our intuitive processors (a.k.a. our "gut") try and determine the value of information

- **Choosing to gather more information because it's "cheap" and focusing on the positive test results.**
  - Failing to think about the risks information won't address, and how much the information is really worth for the uncertainty it will resolve.
  - Failing to think about that the test results could tell you that the final outcome could be bad.
  - Forgetting about imperfect information (false positives & negatives)
- **There's nothing to test, just "Do the project now".**
  - Failing to think that information could lead you to better alternatives or give you options that can avert some of the bad outcomes in the future.

## What should do…

- Consider potential expert biases and carefully structure the assessment order for imperfect information to obtain logically consistent values.

  - Start with current uncertainty assessment (state of nature), then assess test results/reliability based on each of the possible states.
  - Condition before assessing. Help the expert think about reliability and list situations that could cause the false positives before assessing the probability (test says “trap”, when there is no trap).

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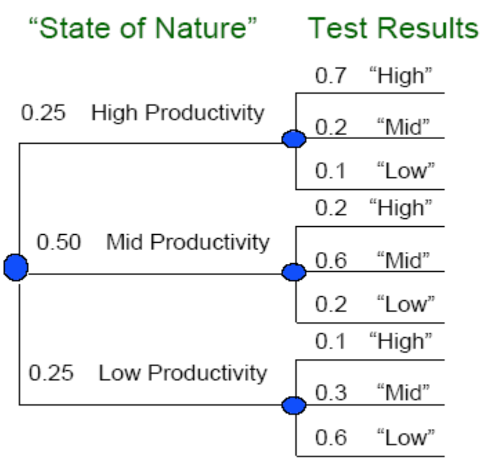
## Conditioning is especially important as the assessment gets more complex.

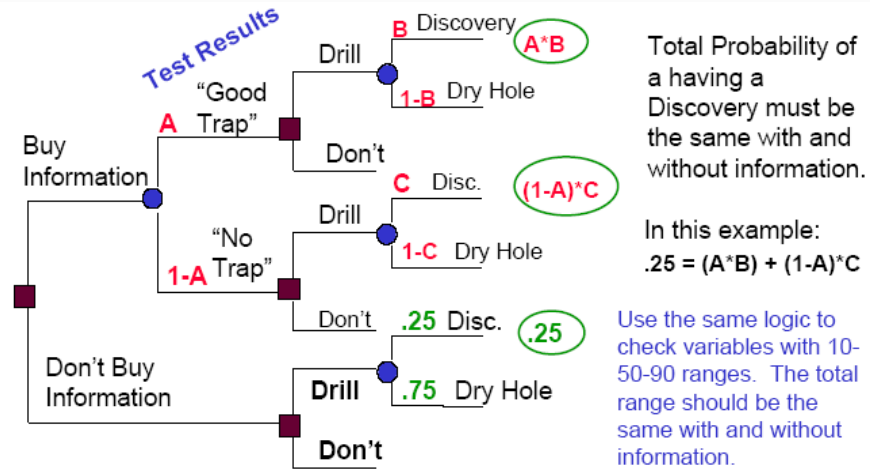



Example of assessing the probabilities on a pilot project given the “state of nature” on reservoir productivity.“

**Before assessing values: need to have the expert think about what could give “mid” or “low” test results if the field will actually have high productivity.**

“State of Nature” is your current assessment of the uncertainty without the test.

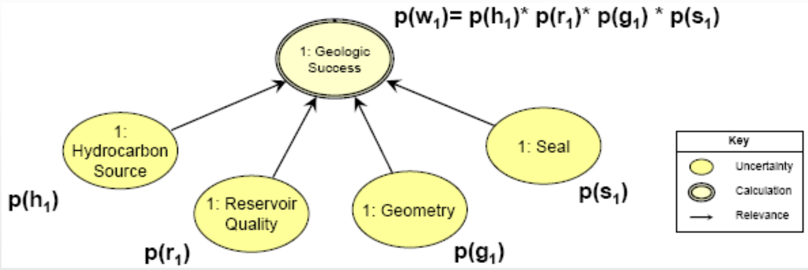
## Check the probabilities or ranges with and without information to make sure that the assessments and logic are correct.




## VOI Analysis Pattern in E&P

- Through exploration to development, Through exploration to development, three distinct patterns may be identified.
- Seismic & Drilling
  - » Seismic – 2D, 3D seismic processing
  - » Hydrocarbon presence geologic dependencies (well or seismic)
- Appraisal & Development:
  - » Concept/contract selection

## The probability of geologic success is comprised of four factors.




- **Hydrocarbon Source**: Hydrocarbons in correct phase and quality were generated.
- •**Reservoir Quality**: Reservoir rock of appropriate permeability and porosity is present.
- •**Geometry**: Geometry of structure is as represented by seismic and slight changes would not jeopardize the accumulation of hydrocarbons.
- •**Seal**: Seal exists with sufficient permeability to retain hydrocarbons

## Example 1:Buying Seismic Info

Seismic addresses 1 or 2 components of Geologic Risk
**Geologic Risk** = Chance of finding produceable hydrocarbons =
Trap * Reservoir * Hydrocarbon Source* Timing & Migration
This approach breaks geologic risk into the key components, or risk elements, that experts can think clearly about and assess.

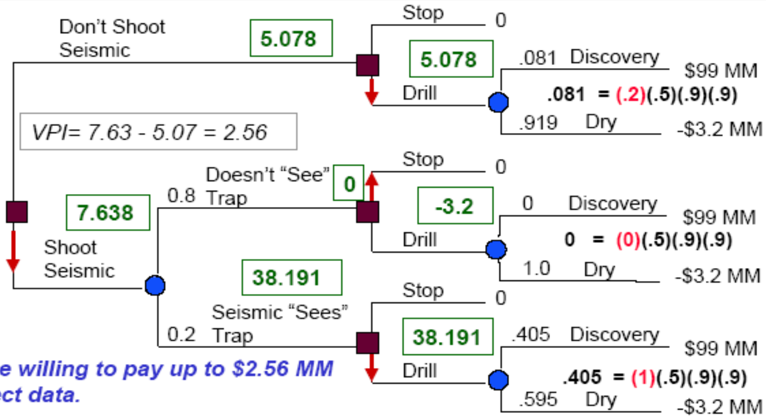
## Probability of Discovery

Geologic Risk = Trap * Reservoir * Source * Timing

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Without Information** | = | .2 | * | .5 | * | .9 | * | .9 | = | .081 |
| **With Information** | = | .7 | * | .5 | * | .9 | * | .9 | = | .284 |
| With Perfect Information | = | 1.0 | * | .5 | * | .9 | * | .9 | = | .405 |

*For this project, experts felt that seismic would resolve the trap risk, but not the reservoir risk. Rather than assess test reliability, we asked the experts about the data quality in this area. They felt that even the best quality data in the area could only improve the trap risk to 0.7.*

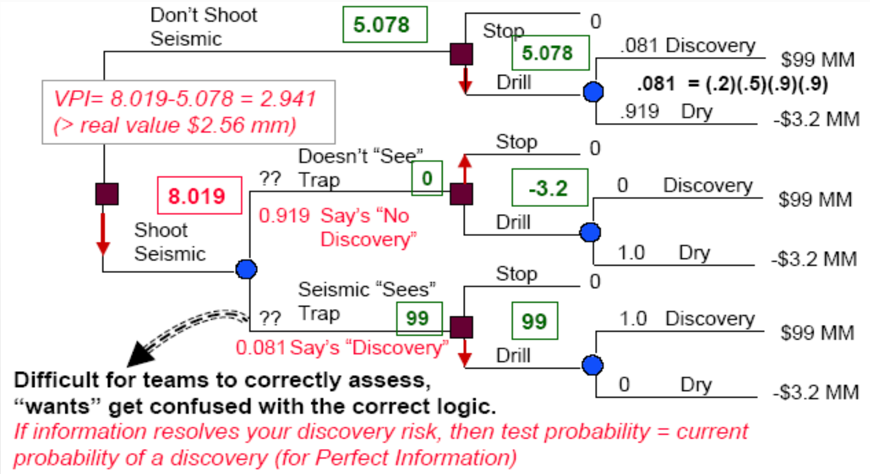
## Value of Perfect Information sets the maximum that you would pay for any information.



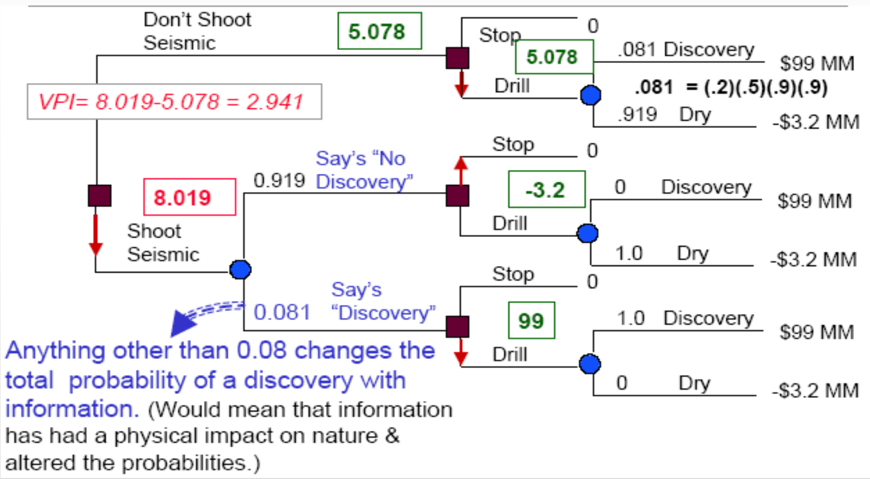

***Would be willing to pay up to $2.56 MM for perfect data.***

***If seismic costs more than that, the decision is clear.***

## Assuming that information will resolve all of your uncertainty over states the real Value of Information.




## Assessing a probability that is inconsistent with the logic of the problem will gives an incorrect Value of Information.

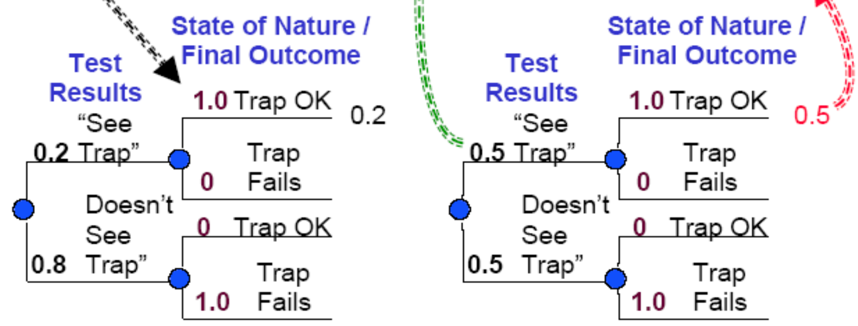


## For imperfect information, assessing values in the wrong order often yields biased or incorrect results.

Experts will tend to focus on what they want to happen and forget that information is imperfect (has false positives and negatives).

Poor framework to logically assess the test results.

Can lead to information changing the state of nature probability.

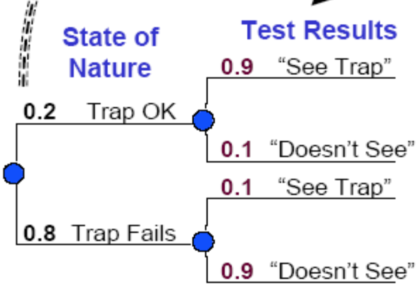



## Assess the state of nature first, then the test reliability to get quality results

1. Assessing the State of Nature first allows yields an unbiased view of the current risks.

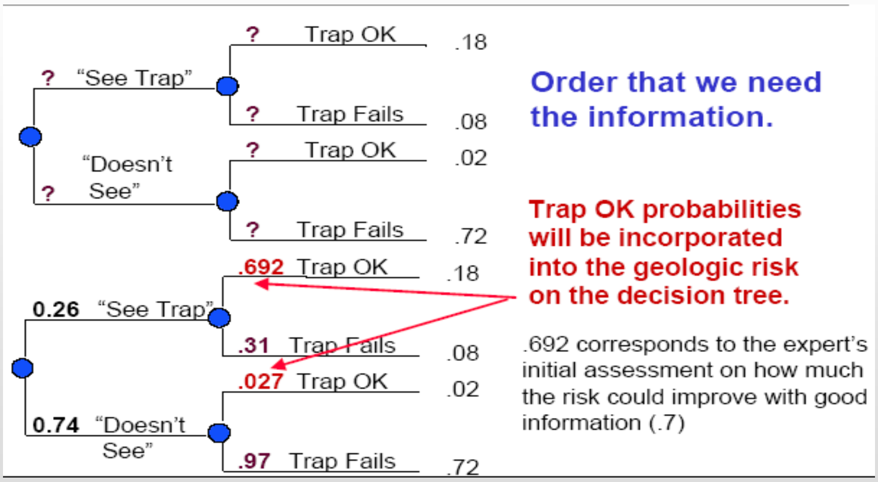
2. Next, assess test results, or reliability, dependent upon the state of nature.

Expert should discuss factors that could cause a poor test result in the situation where Trap is OK. This helps to de-bias and give a logical basis for the probabilities.

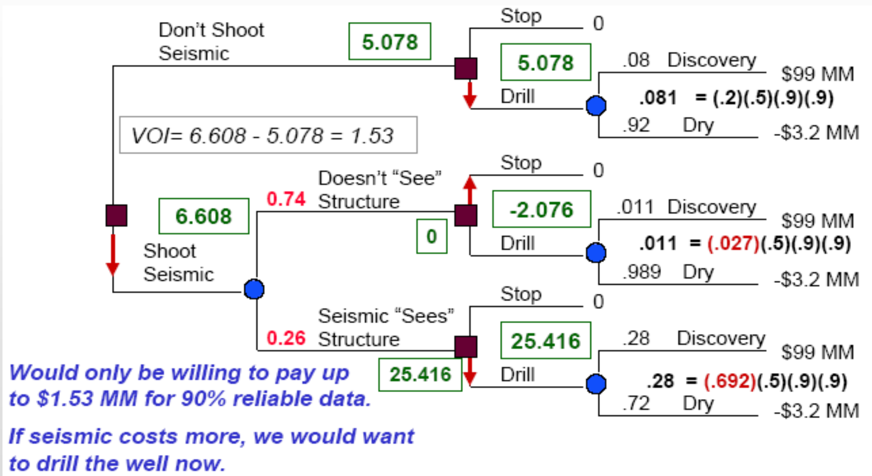



**Note:**
**The test results or, information reliability, does not have to be symmetric.**

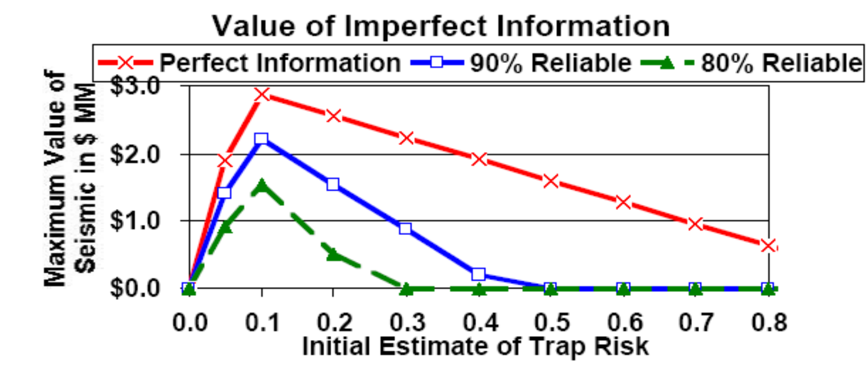
## Flipping the tree puts information in the right order to use it in our decision tree.




## In this seismic example, the value of 90% reliable information is much less than perfect information.

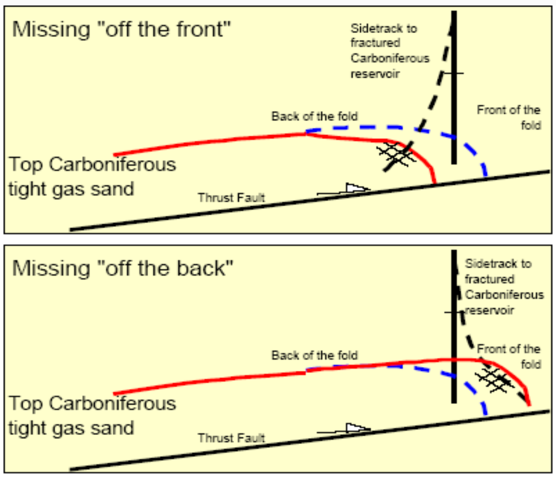


## Sensitivity to Probability helps experts review their assessments and the impact on the decision.




Sensitivity to probability allows experts to see if small changes in their assessment would impact the decision. Also, they can help validate whether the analysis is consistent with their information and judgement:

## Buying a Seismic Line Example: Buying a Seismic Line May Change May Change Where Where to Place Well




**Strategic Questions:**

***What is the value of PSDM?***

***Is it worth buying at $60K?***

## VOI Uncertainty Table

| | Key Uncertainty |
|---|---|
| | Location of Highly Fractured Fold |
| Decisions Which May Change (Impact of Info) | If/Where to Position Well |
| Information Alternatives | • As-is 2D seismic<br>• PSDM of 2D seismic<br>• Pilot hole |

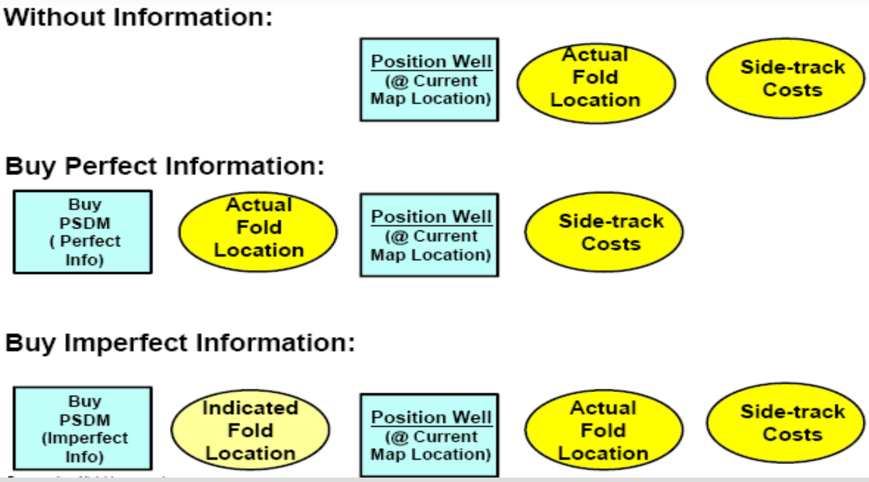
**Key VoI Questions:**

*Most uncertain about?*

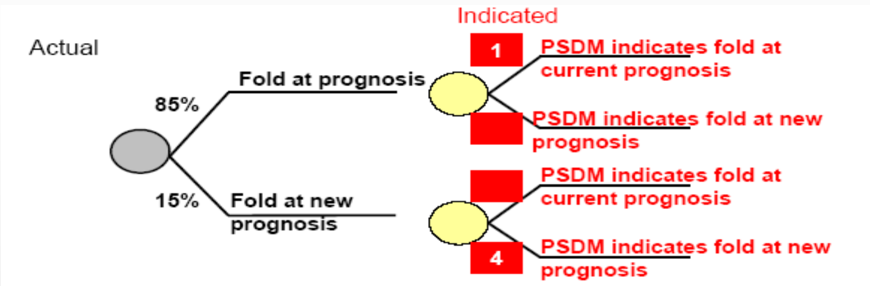
*What decision may change?*

*How reliable is the info & is it worth the cost?*

## Decision & Risk Timelines Structure



## The VOI Reliability Interview for Imperfect Information



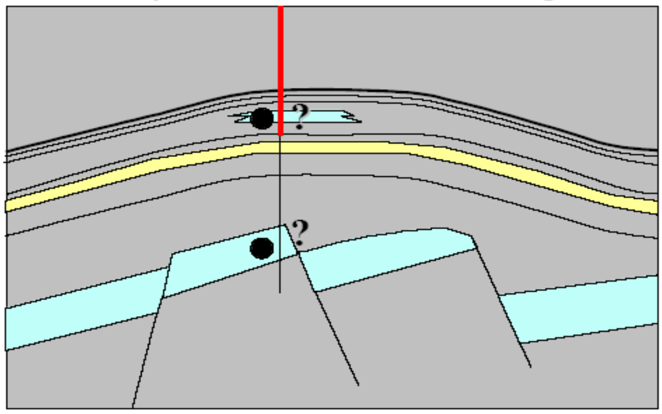

Question to "1" probability: "Given the Scoobydo fold actually is where it is currently mapped, what is the chance the PSDM will indicate the same location?"

…….

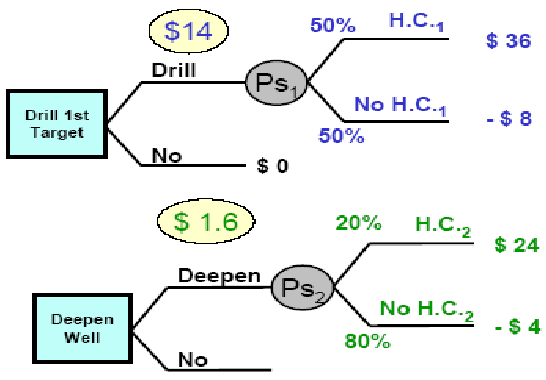
Question to 4 probability: "Given the Scoobydo fold actually is at a new prognosis (different location from its currently mapped location), what is the probability that PSDM will indicate the new prognosis (location)?"

## Example 2: Deepening a Well with H.C. Presence Geologic Dependencies

*Information can be gained while drilling multi-targeted wells to assist with decision to proceed or not. But will it change a decision?*

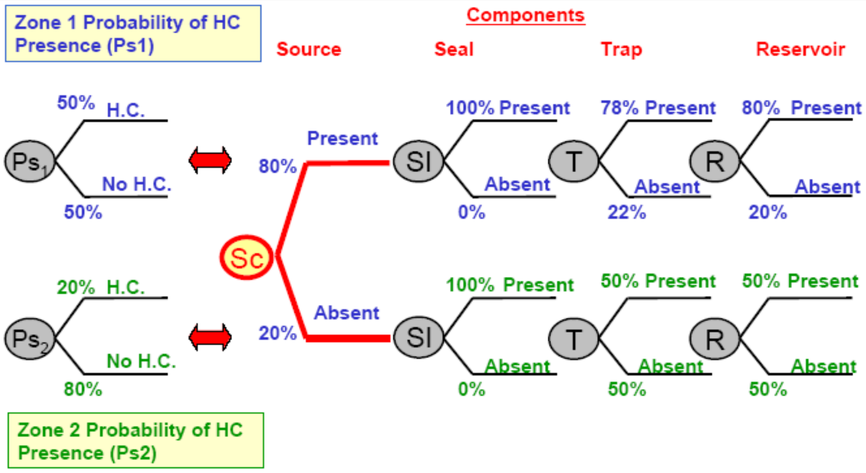


## Independent targets are relatively easy to evaluate.

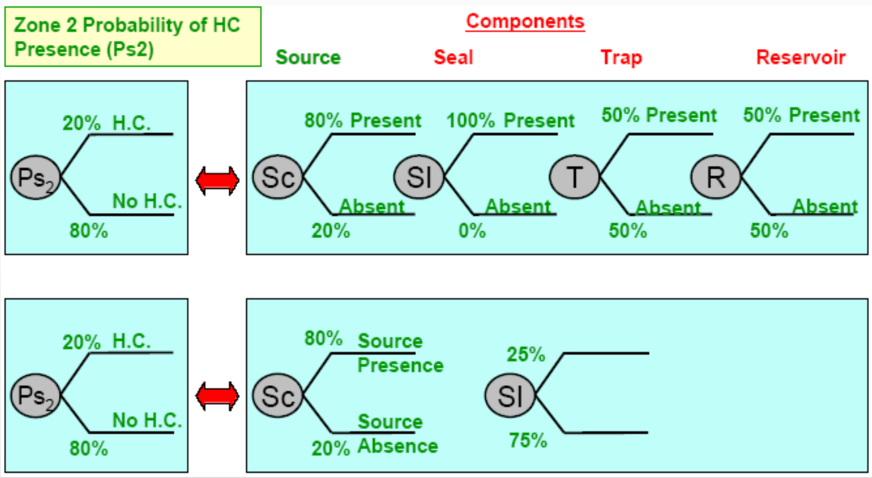



***What happens when target 1 tells us nothing about target 2?***

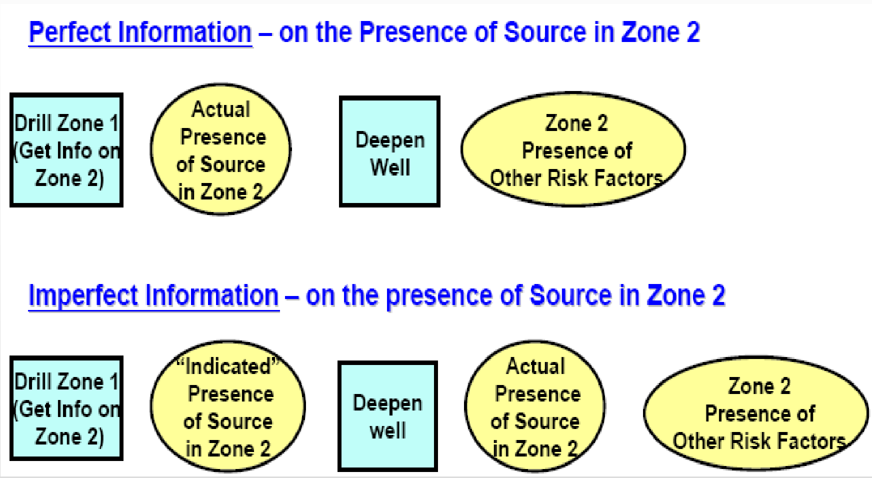
## Splitting up the components of HC presence shows the shared risks



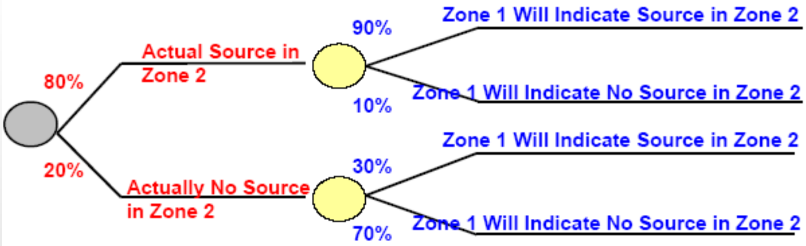
## To determine the impact of the info, the interdependent variable(s) is isolated.




## The Decision and Risk Timelines show the decision trees to be evaluated.



## A Reliability Interview is required to determine the impact of the information provided by Zone 1 on the underlying uncertainty of H.C. source in Zone 2.




*Interview Question: If there actual is the presence of source in Zone 2, what is the probability that Zone 1 will indicate the presence of source in Zone 2? (I.e. How reliable is info on Zone 1 for indicating the presence of source in Zone 2?)*

---

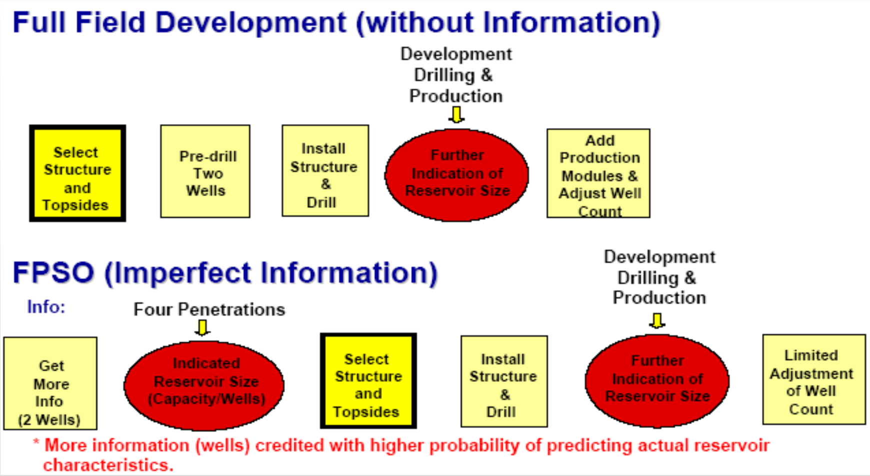
## Example 3: Appraisal & Development Concept Selection

Choice of Development Concept…

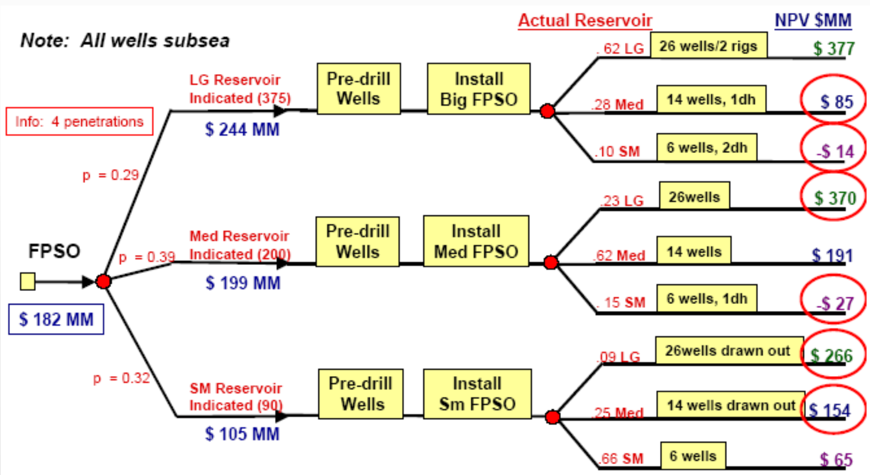
Trying not to over capitalize nor undersize the development scheme.

- » Tension Leg Platform
- » Spar
- » Floating Production Storage Offtake

## Concept Selection: The Development Decision (Getting to Know the Nine Branch Tree)




## What happens when adjustments have to made (When what you see is not whatyou get)?



## Recognizing the consistency in the patterns is the key to Upstream VoI

Easy to make mistakes

- » Solving in your head
- » Non intuitive
- » Not quantifying uncertainty
- » Poor decision trees
- » No application of Bayes' Law.

Recognizing the decision pattern ensures consistency & quality in the approach

## Case Study I

## Example: Value of Imperfect Information

- We have discovered oil in an offshore prospect
- Studies indicate reserves in 5-25 MM STB range, with probabilities in table
- Two options
  - Design facilities based on information available
  - Drill delineation wells to improve probability and reservoir size estimates

## NPV of Each Field Size and Facility, MM$

| Field Size | Probability | Size A | Size B | Size C |
|---|---|---|---|---|
| Large | 0.30 | 290 | 350 | 450 |
| Medium | 0.45 | 90 | 210 | 160 |
| Small | 0.25 | 60 | 35 | 50 |

## Questions to Answer

- Determine **most economical facility size** without further information, using EMV
- Calculate expected value of perfect information using EMV and EOL. Based on EVPI, determine **maximum amount** we can pay to acquire additional information

## Questions to Answer

- Calculate **expected value of imperfect information** if we decide to drill delineation wells costing $15MM before we decide on size of facilities
- Geologists' beliefs about delineation wells
  - Probability 90% that we will identify large reservoir if that's what is actually there
  - Probability 60% that we will identify medium reservoir if that's what is actually there
  - Probability 30% that we will identify small reservoir if that's what is actually there

## EMV Using Available Information

| Field Size | Probability | NPV of Field Size and Facility, MM$ | | |
|---|---|---|---|---|
| | | Size A | Size B | Size C |
| Large | 0.30 | 290 | 350 | 450 |
| Medium | 0.45 | 90 | 210 | 160 |
| Small | 0.25 | 60 | 35 | 50 |
| **EMV** | | 142.5 | 208.3 | 219.5 |

## Expected Value of Perfect Information (EVPI)

| Field Size | Probability | NPV of Field Size and Facility, MM$ | | |
|---|---|---|---|---|
| | | Size A | Size B | Size C |
| Large | 0.30 | | | 450 |
| Medium | 0.45 | | 210 | |
| Small | 0.25 | 60 | | |
| EVPP | | 15 | 94.5 | 135 |

EVPP = 0.3x450+0.45x210+0.25x60 = $244.5MM

EVPI = 244.5 - 219.5 = $25MM

## Expected Opportunity Loss (EOL)

| Field Size | Probability | NPV of Field Size and Facility, MM$ | | |
|---|---|---|---|---|
| | | Size A | Size B | Size C |
| Large | 0.30 | 160 | 100 | 0 |
| Medium | 0.45 | 120 | 0 | 50 |
| Small | 0.25 | 0 | 25 | 10 |
| **EOL** | | 102 | 36.25 | 25 |

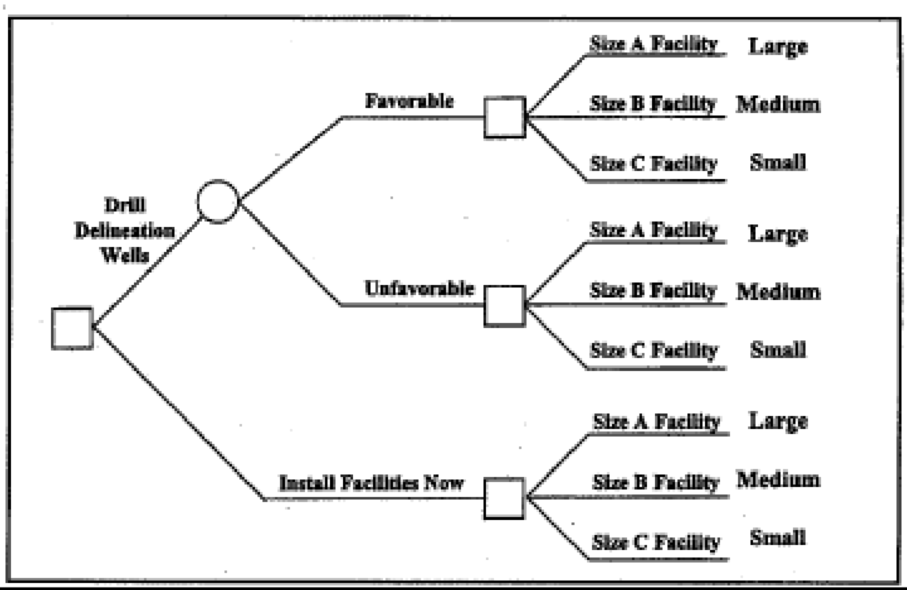
Confirms selection of size C facility
EVPI = $25MM same as calculated by EMV method

## Expected Value of Imperfect Information (EVII)

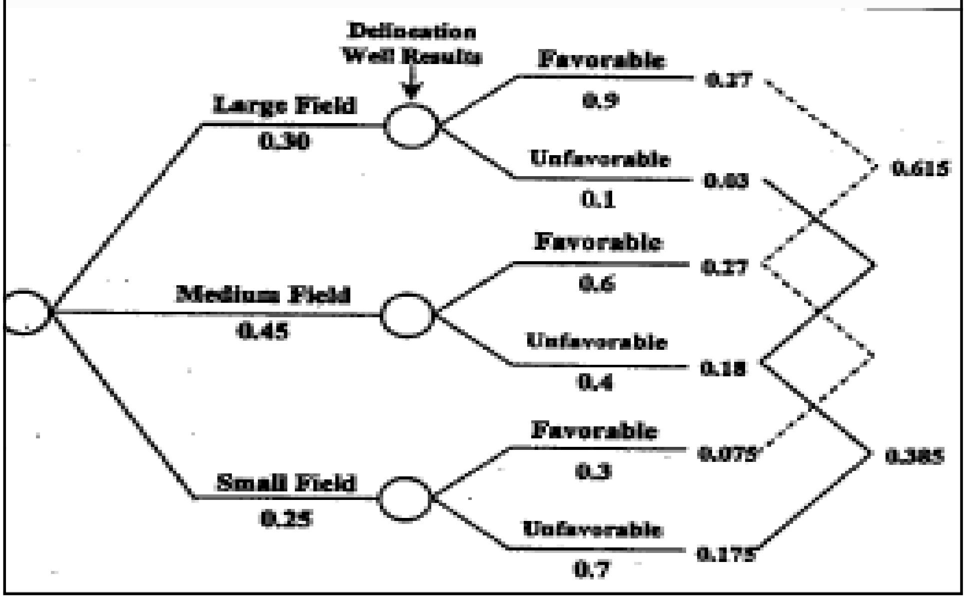
To calculate EVII, consider two alternatives

- Install platform without acquiring additional information (calculations above)
- Drill delineation wells and decide on platform size based on information they provide

## Decision Tree for Option to Drill Delineation Wells




## Partial Tree for Result of Delineation Wells



## Assessment of Probabilities of Different Field Sizes from Partial Tree

- Note joint probabilities of favorable outcomes when delineation wells are drilled are
  - 0.3x0.9 = 0.27 … large field
  - 0.45x0.6 = 0.27 … medium field
  - 0.25x0.3 = 0.075 … small field
- Total probability of favorable outcome = 0.27 + 0.27 + 0.075 = 0.615 (and probability of unfavorable outcome is 1 – 0.615 = 0.385)

## Rearrangement of Tree (Inversion)

- Posterior probabilities and EMV's shown in tables and on inverted tree
- Process demonstrates application of Baye's rule (see Mian, vol.II, pp. 94-99)

$$P(A_i / B) = \frac{P(B / A_i) x P(A_i)}{\sum_{i=1}^{n} P(B / A_i) x P(A_i)}$$

## Application of Baye's Rule

$$P(A_i / B) = \frac{P(B / A_i) x P(A_i)}{\sum_{i=1}^{n} P(B / A_i) x P(A_i)}$$

- ***$P(A_i/B)$*,** posterior probabilities, represent probabilities that reservoirs will be small, medium, or large (***$A_i$***), given results of delineation drilling (***B***)
- ***$P(B/A_i)$*** represent probabilities that delineation drilling result (***B***) will be favorable or unfavorable, given probabilities (***$A_i$***) that reservoirs are small, medium or large
- ***$P(A_i)$*,** prior probabilities, represent original probabilities that reservoirs will be small, medium, or large

## Calculation of NPV, Delineation Wells Favorable

| Delineation Wells Favorable | | | | |
|---|---|---|---|---|
| Field Size | Posterior Probability | NPV of Each Field Size and Facility, MM$ | | |
| | | Size A | Size B | Size C |
| Large | 0.27/0.615 | 290 | 350 | 450 |
| Medium | 0.27/0.615 | 90 | 210 | 160 |
| Small | 0.075/0.615 | 60 | 35 | 50 |
| EMV | | 174.5 | 250.12 | 273.90 |

Select size C if delineation well results favorable

## Calculation of NPV, Delineation Wells Unfavorable

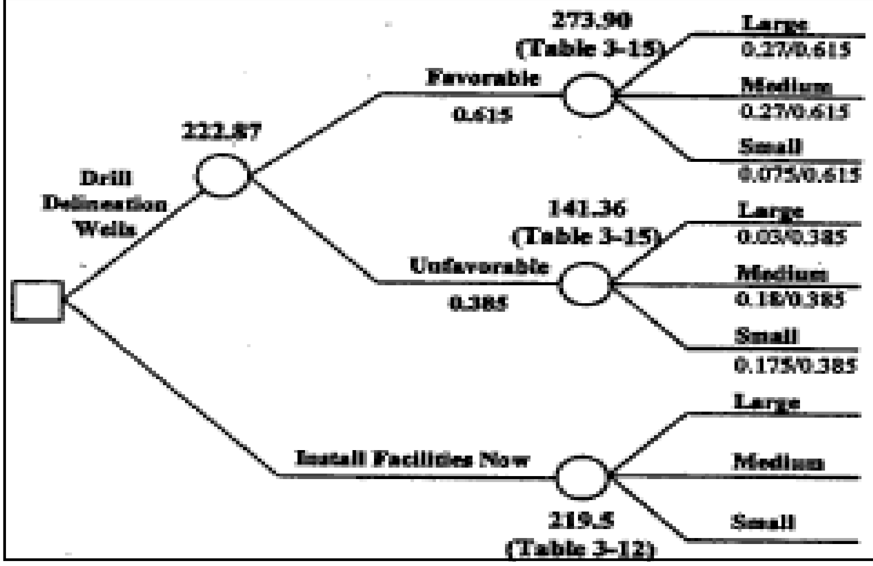
| Delineation Wells Unfavorable | | | | |
|---|---|---|---|---|
| Field Size | Posterior Probability | NPV of Each Field Size and Facility, MM$ | | |
| | | Size A | Size B | Size C |
| Large | 0.03/0.385 | 290 | 350 | 450 |
| Medium | 0.18/0.385 | 90 | 210 | 160 |
| Small | 0.175/0.385 | 60 | 35 | 50 |
| EMV | | 91.95 | 141.36 | 132.60 |

Select size B if delineation results unfavorable

## Value of Imperfect Information

- Table indicates we should select size C facility if delineation well results favorable (EMV = $273.9MM)
- Table indicates we should select size B facility if delineation well results unfavorable (EMV = $141.36MM)

## Inverted Tree for Result of Delineation Wells




## Delineation Well Decision

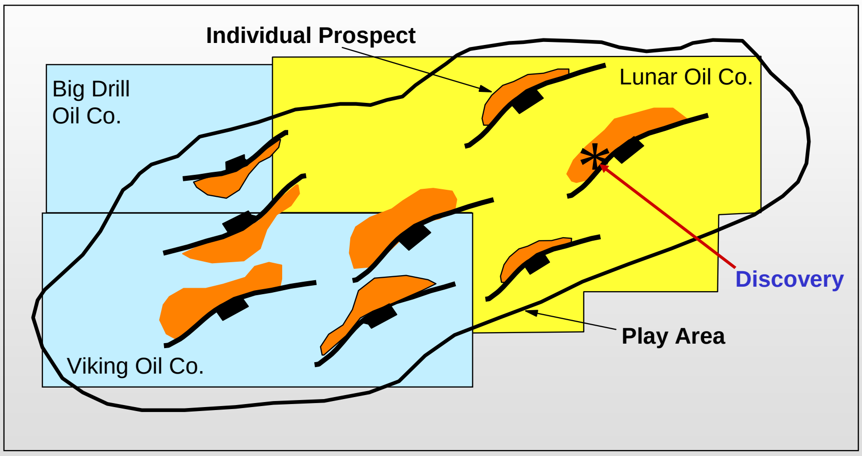
- Expected payoff with imperfect information, EPII, if we drill delineation wells

  EPII = 0.615x273.90 + 0.385x141.36 = $222.87MM

- Expected value of imperfect information,
  EVII = 222.87 - 219.50 = $3.37MM
- We should pay no more than $3.37MM to drill delineation wells, which means ***we cannot support the proposed $15MM drilling budget***
- Since EVPI is $25MM, value of information from delineation wells, $3.37MM, considerably less than value of perfectly reliable results

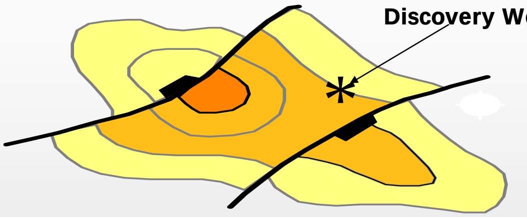
# Case Study II

## Lunar Oil Company has made a discovery – should they appraise or go straight to development?




**What is the value of acquiring appraisal information?**

## Reserve uncertainty

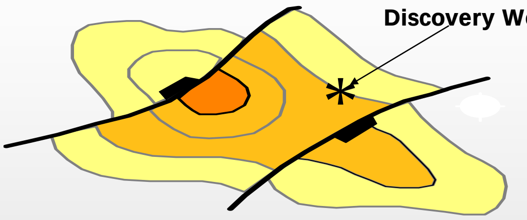



You are evaluating whether or not you should drill an appraisal well (cost $MM 5) before developing an oil discovery.

The key uncertainty for this development is oil reserves. Your reservoir engineer has provided you with the following lognormal reserve estimates:

| | | |
|---|---|---|
| p10 (Low) | 80 MMbbls | (prob .3) |
| p50 (Medium) | 130 MMbbls | (prob .4) |
| p90 (High) | 200 MMbbls | (prob .3) |

## Reserve uncertainty




| Concept Selection | |
|---|---|
| Fixed Platform Development | Greater than 180 MMbbls |
| Floating Production, Storage and Offtake (FPSO) | Greater than 110 MMbbls, but less than 180 MMbbls |
| Tie-back to Existing Facility | Less than 110 MMbbls |

## CAPEX and Production Rate for each concept

| Concept | CAPEX $MM | Production Rate (bbls/day) |
|---|---|---|
| Fixed Platform | 450 | 100,000 |
| FPSO | 300 | 50,000 |
| Tie-back | 80 | 20,000 |

## NPV for each concept, MM$

| Reserve size (MMbbls) | Fixed Platform | FPSO | Tie-back |
|---|---|---|---|
| 200 | **276** | 257 | 177 |
| 130 | 138 | **163** | 146 |
| 80 | 16 | 69 | **103** |

## Information from Appraisal Well

- Appraisal drilling will tell you net effective pay and thus provide some information on reserves.
- The decision that might change as a result of the information is the **concept selection**.

## Information from appraisal Well

**Data from the expert:**

**If actual reserves are 200 MMBO** (Fixed Platform)

75% chance of predicted reserves > 180 MMbbls (Fixed Platform)
20% chance of predicted reserves > 110 MMbbls (FPSO)
5% chance of predicted reserves < 110 MMbbls (Tie-back)

**If reserves are 130 MMBO** (FPSO development)

15% chance of predicted reserves > 180 MMbbls (Fixed Platform)
75% chance of predicted reserves > 110 MMbbls (FPSO)
10% chance of predicted reserves < 110 MMbbls (Tie-back)

**If reserves are 80 MMBO** (Tie-back development)

5% chance of predicted reserves > 180 MMbbls (Fixed Platform)
10% chance of predicted reserves > 110 MMbbls (FPSO)
85% chance of predicted reserves < 110 MMbbls (Tie-back)