# Estimation of Oil Land Area by Using Bayes' Theorem

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## Abstract

*Petroleum exploration is a high risk business. Consulting geologists predicts the probable existence of oil based on the geological evidence such as reservoir rocks, source rocks, sealed rocks, trap, recovery factor and generation timing to obtain a better estimation of oil. To predict the probable existence of oil, it is very hard decisions because exploration of hydrocarbons is a high-risk venture and geological concepts are uncertain with respect to structure, reservoir seal, etc., . Bayes' theorem is used to compute the prior probability to make the decision of drill the oil or sell the land upon the given user facts. This system also presents the method of computing posterior probabilities from prior probabilities using Bayes' theorem to get decision tree. By using this system, people in petroleum-exploration field will get the knowledge of the essential factors for them.*

***Keyword:*** decision support system, Bayes' theorem, prior probabilities, posterior probabilities, decision tree

## 1. Introduction

Decision support system is the powerful tool for determining an optimal course of action to reduce the level of uncertainty about the outcome of decision. Bayes' theorem is widely used for decision support system and has been applied to many practical decision-making problems. Petroleum industry focuses on calculating the value of information using Bayes' theorem to determine the better estimation of oil existence. Petroleum resources are the estimated quantities of hydrocarbons naturally occurring on or within the Earth's crust. An important purpose of risk assessments in petroleum exploration is estimating the probability of discovery prior to drilling a prospect.

Decisions related to petroleum exploration are very complex because of the high requirement of information involved in the process. It is necessary to define the information associated with important decisions such as geologic prospect or seismic survey. People have hard decision facing with uncertainty, so they need help to make the right decision. When the process of searching a hydrocarbon involves many steps, this system reduces the number of steps required to reach a solution.

This paper describes evidence of possible economically recoverable hydrocarbons. This paper is intended to develop the decision support system for the probable existence of oil land area before drilling. This is an alternative method of geological risk-evaluation that determines whether to drill for oil in a particular location and how likely is oil there before drilling. This system grows up the agility of the decision making.

## 2. Related Areas and Problem Issues

Petroleum exploration is a high risk business involving large elements of risk and uncertainty. In research on oil prospect exploration decision making, Siti.H.S [10] proposed the petroleum prospect probability evaluation of southern Mexico by using Bayes' theorem and calculated to obtain prospect probability for the potential accumulation for zones A to D. Hiller/Libernan [5] presented the basic principles of decision making with experimentation and described the decision trees, a useful tool for depicting and analyzing the decision process when a series of decision needs to be made.

Chris.M [2] shows that the definition and discussion of the probability. It explains the details of working-steps for probability with examples. Genny.G [4] opens an opportunity for investigation of the flow properties of the hydrocarbon saturated reservoirs. Their approach aims to get more accurate-data for reservoir rocks through the seismic waves. Galli.A [3] gives some basic information about decision trees which provide a useful way of visually displaying the problem.

## 3. Probability Concepts in Petroleum Exploration

**Multiplication theorem**

$P(A \cap B) = P(A) \times P(B|A)$
$P(A \cap B \cap C \cap D) = P(A) \times P(B) \times P(C) \times P(D)$

The probability of $P(A \cap B)$ is equal to the product of their individual probabilities. This theorem is applied to illustrate the product of several geological independent factors all of which must be present in order to estimate discovery probability.

**Conditional Probability**

$P(A | B_n) = P(A \cap B_n) / P(B_n)$

The probability of $P(A | B_n)$ of an event A may depend on a second event B. Conditional probability is calculated by multiplying the probability of the preceding event by the updated probability of the succeeding event.

**Total Probability**

$P(A) = \sum_{n=1}^{N} P(A|B_n) P(B_n)$

**Bayes' theorem**

$$P(B_n|A) = \frac{P(A|B_n)P(B_n)}{P(A|B_1)P(B_1) + \cdots + P(A|B_n)P(B_n)}$$

Bayes' theorem relates the conditional and total probabilities of events A and B. The value of geological concept can entered and the posterior probability distribution of the compositional fractions can be obtained by applying Bayes' theorem. Bayes' theorem is used for obtaining the better estimates of the reservoir.

## 4. Prior Probability Factors

The prior probability depends on the geologic factor's physical characteristics. It calculates from user's choice of predefined options on this system. The probability assigned can range from 0.0 to 1.0, which means 0% certainty and 100% certainty respectively. The sum of two prior probabilities (probabilities of oil and dry) must equal to 1. This probability is the product of these elements in risk factor equations.

Risk factor =reservoir × source × sealed × trap × Recovery factor × timing

This equation is evaluated with respect to presence of its sub-factors (1) probability of reservoir [i.e., porosity, permeability, pore volume, grain size, saturation of rocks]; (2) probability of source rocks [i.e., TOC percent]; (3) sealed rocks [i.e., rocks must have top sealed and bottom sealed]; (4) probability of trap [i.e., mapped structure, effective seal mechanism] (5) recovery factor and (6) generation timing.

Source rocks must have higher TOC (Total Organic Carbon) percentage because this causes the existence of hydrocarbon. Sealed rocks must have top sealed and bottom sealed to prevent the escaping of the hydrocarbon.

Trap is to prevent the oil from leaking away. The study of information how hydrocarbons move from source to reservoir is called recovery factors. Usually, 60% of petroleum can get from a well so this can assume nearly 0.6. Generation timing involves assessing the thermal history of the source rock in order to make the predictions of the amount and timing of hydrocarbon generation. Its value is used to be a constant number 0.7.

Petroleum exploration is calculated on the basis of the geological events until the present day by using the risk factor equation.

## 5. Probability of Hydrocarbons Using Bayes' theorem

This system has two possible actions under consideration: drill for oil or sell the land. In this system, risk factor equation can be used to estimate the prior probabilities of oil by choosing the current geological facts and it works as the consulting geologist.

### 5.1. Calculation of Prior Probability

The probabilities for the respective states of nature provided by the prior distribution are called the prior probabilities. Risk factor equation is calculated by the user input for six facts, important facts for getting oil. For example, assume probabilities of reservoir, source, sealed, trap, recovery factor and timing are 0.88, 0.71, 1, 1, 0.6 and 0.7.

*Risk factor =reservoir × source × sealed × trap × Recovery factor × timing*

$P(\text{Risk factor}) = 0.88 \times 0.71 \times 1 \times 1 \times 0.6 \times 0.7 = 0.26$

The prior probability of oil is 0.26 and the probability of dry is (1 – 0.26) = 0.74, respectively.

### 5.2. Bayes' Decision Rule

User must estimate price of selling-land, drilling cost and possible profit. *Example*, another oil company has offered to purchase the land for 90,000. But, company can drill for oil itself. The cost of drilling is 100,000. If oil is found, the profit will be 800,000. This paper makes the decision of whether to drill or sell based on given data.

| Alternative | State of Nature (,000) Oil | Dry |
|---|---|---|
| Drill | (800-100)=700 | -100 |
| Sell | 90 | 90 |
| Prior Probability | 0.26 | 0.74 |

**Table 1: Payoff table for the decision analysis**

E [Payoff (drill)] = 0.26(700) + 0.74(-100) = 108
E [Payoff (sell)] = 0.26(90) + 0.74(90) = 90

Bayes' decision rule calculates the expected value of the payoff for each of the possible actions. Choose the action with the maximum expected payoff. Since 108 is larger than 90, the alternative action selected is to drill for oil.

## 5.3. Decision Making With Experimentation

Additional testing can be done to improve the preliminary estimates of the probabilities. A seismic survey obtains seismic soundings that estimate whether the geological structure is favorable to the presence of oil. It has two categories: USS (Unfavorable) and FSS (favorable) seismic soundings; oil is unlikely and likely. User must estimate the seismic cost and the probabilities of the seismic survey, Favorable (FSS) or Unfavorable (USS). *Example*:
P(USS|State=Oil)=0.4;P(USS | State=Dry)=0.8.
Let seismic cost is 30,000.

| State of Nature | Prior Probability | FSS | USS |
|---|---|---|---|
| Oil | 0.26 | (1-0.4)=0.6 | 0.4 |
| Dry | 0.74 | (1-0.8)=0.2 | 0.8 |

**Table 2: The conditional probabilities**

In this system, n=2; $B_1$=Oil and $B_2$=Dry and A=USS (or) FSS. According to Bayes' theorem,

$$P(Oil|State=USS)=\frac{P(USS|Oil)P(Oil)}{P(USS|Oil)P(Oil)+P(USS|Dry)P(Dry)}$$

$$=\frac{0.4*0.26}{0.4*0.26+0.8*0.74}=0.1494$$

P(Dry|State=USS)= 1 – 0.1494 = 0.8506

$$P(Oil|State=FSS)=\frac{0.6*0.26}{0.6*0.26+0.2*0.74}=0.5132$$

P(Dry|State=FSS)= 1 – 0.5132 = 0.4868

Then, system also calculates the probability of unfavorable and favorable seismic survey. According to Total Probability,
P(FSS) =P(FSS|Oil)P(Oil)+P(FSS|Dry)P(Dry)
= (0.6) (0.26) + (0.2) (0.74) = 0.3
P(USS) = (0.4) (0.26) + (0.8) (0.74) = 0.7

| Posterior Probabilities | | State of Nature | |
|---|---|---|---|
| | | Oil | Dry |
| FSS | 0.3 | 0.5132 | 0.4868 |
| USS | 0.7 | 0.1494 | 0.8506 |

**Table 3: The posterior probabilities**

Bayes' decision rule calculates the expected payoffs with the posterior probabilities instead of the prior probabilities for the seismic survey. By using the payoffs from Table 1 and subtracting the seismic cost,
E [Payoff (drill|USS)] = (0.1494) (700) + (0.8506) (-100) - 30=-10.48
E [Payoff (sell|USS)] = (0.1494) (90) + (0.8506) (90) - 30=60
E [Payoff (drill|FSS)] = (0.5132) (700) + (0.4868) (-100) - 30=280.56
E [Payoff (sell|FSS)] = (0.5132) (90) + (0.4868) (90) - 30=60

The objective is to maximize the expected payoff. Since 280.56 is the largest expected payoff, the alternative action selected is to drill for oil if finding is favorable seismic sounding.

## 5.4 Constructing the decision tree

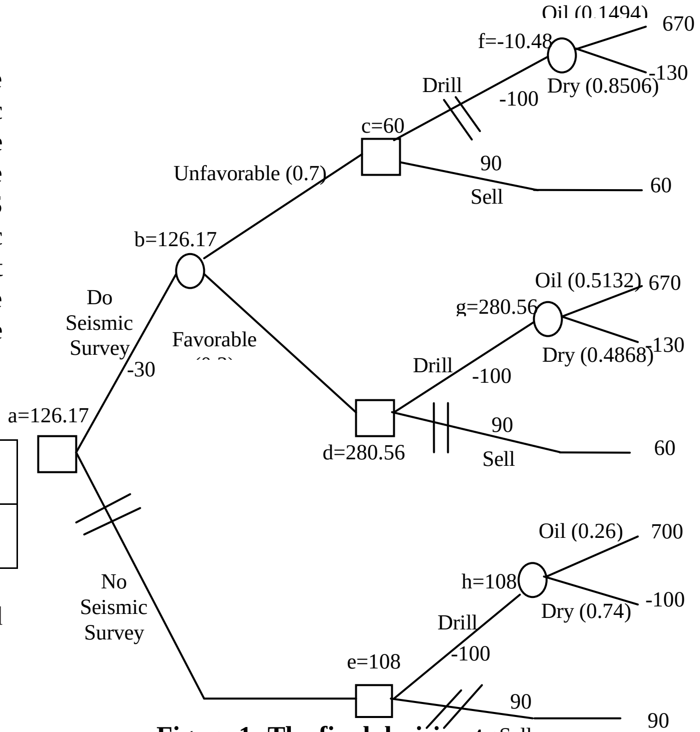


**Figure 1: The final decision tree**

Decision tree includes decision node: represented by squares and chance node: represented by circles. The numbers under or over the branches that are not in parentheses are the cash flows (in thousands of dollars). For chance-fork h, the probabilities are the prior probabilities of these states of nature, since no seismic survey has been conducted to obtain more information. Chance-fork f and g can make a decision to do the seismic survey. The probabilities from these chance-forks are the posterior probabilities of the states of nature, given the finding from the seismic survey.

The first step in constructing decision tree is to insert numbers into the chance-forks f=-10.48, g=280.56 and h=108. (Calculated in Section 5.2 and 5.3) The next step is in decision forks c, d and e.
Fork c: 60 > -10.48; so choose the sell alternative.
Fork d: 280.56 > 60; so choose the drill alternative.
Fork e: 108 > 90; so choose the drill alternative.
EP = (0.7)(60)+(0.3)(280.56)=126.17 for fork b
Fork a: 126.17 > 108; so choose Do seismic survey.

The double dashes have closed off the undesired paths. Bayes' decision rule says to follow only the open paths from left to right to achieve the largest possible expected payoff.

## 6. System Design and Implementation

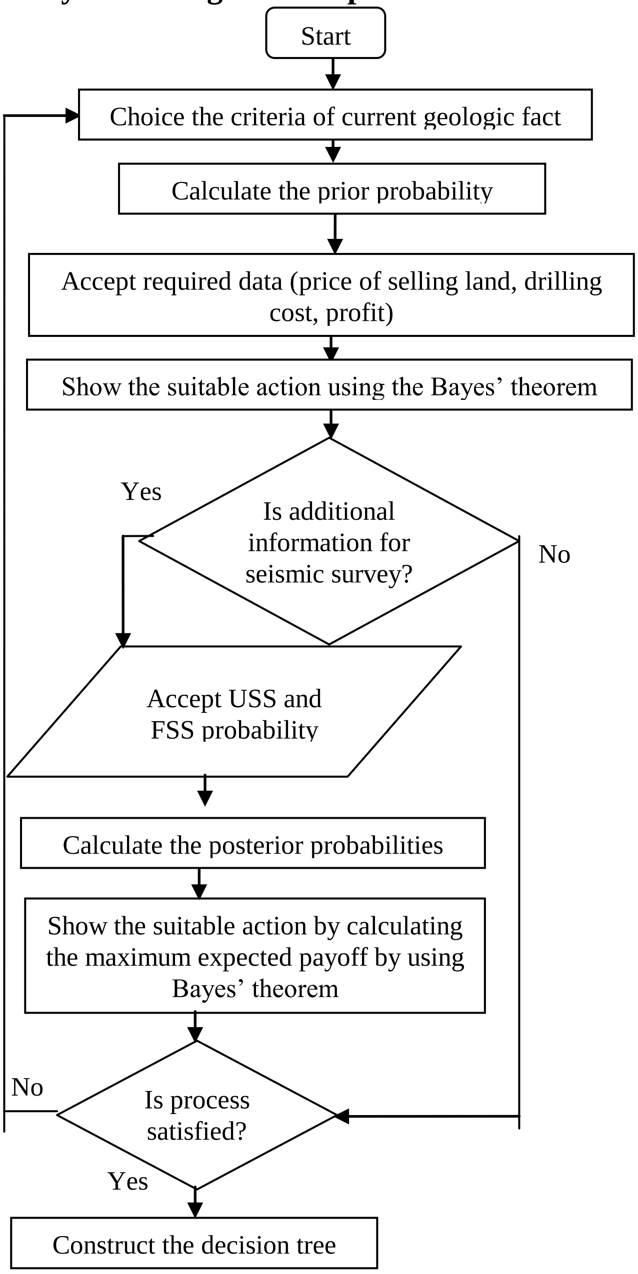


**Figure 2: System design**

**Implementation Steps**

1. Start the problem
2. User is chosen the given geologic factors compared with the current geologic factors
3. Calculate the prior probability using the chosen user facts
4. Accept required data from user ( price of selling land, drilling cost, profits)
5. Showing the suitable action by calculating the Bayes' theorem
6. If Seismic information is added, accept the required probability for USS and FSS.
7. Calculating the posterior probability
8. Show the suitable action that is more accurate by using Bayes' theorem
9. Construct the final decision tree

## 7. Conclusions

Decision risk analysis focuses on making decisions so as to maximize the probability of meeting a target. This allows decision theory to be integrated with Bayes' theorem. Oil land survey is a very difficult work of geography subject. Many investors lost their money for searching hydrocarbon. So, this system expects to support the decision makers. Then, users more easily understand the final result by showing the decision tree. For using Bayes' theorem, this system can give that more reliable. This system will be creating as web application. This system can help decision makers to save their time and give best suggestions for their purposes.

## References

[1] Archis.G, "Stochastic Models and Decision Analysis", "UW Industrial Engineering"

[2] Chris.M, "Conditional Probability, Bayes' Theorem, Independence and Repetition of Experiments"

[3] Galli.A, "Comparing Three Methods for Evaluating Oil Projects: Option Pricing, Decision Trees, and Monte Carlo Simulations"

[4] Gennady.G, Dmitry.S, "Reservoir permeability From Seismic Attribute Analysis"

[5] Hiller/ Liberman, "Introduction to Operation Research"

[6] Harbaugh,J, "Probability Methods In Oil Exploration: New York", (269p)

[7] Martin.F, Member.A, "Correlation and Data with Sandstone Core Characteristics"

[8] Newedorp.P, "Decision analysis for petroleum Exploration", (second edition, 606p)

[9] Peebles.Z, "Probability, Random Variables and Random Signal Principles", (fourth edition)

[10] Siti.H, "Influence of different probability based models on oil prospect exploration decision making"

[11] Wehner.H, "Search for source rocks of the crude oils of the Darmo depression"