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From Geological Knowledge to Good Decisions Using Simple Stochastic Models, a North Sea Case Study

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Abstract

The decision process for one of the partners in the development of the Alvheim field is presented. The challenge was to turn relatively small Palaeocene structures consisting of both unproven prospects and proven oil and gas reserves into a field development with a good economic performance. The paper describes the stochastic model that was buildt to support decisions in the early phases of the field development.

To pinpoint the essential elements for a model is difficult task. Not only the characteristics of the field, but also the decisions that the model is supposed to support, must be considered. A simple stochastic model was buildt. An exploration type of approach was used. Essential elements are volume-depth curves and modeling of seismic uncertainty and uncertainty in fluid contacts.

Using the model, it was possible to explore important upside potensial seen in geophysical evaluations and answer *if* and *in what sequence* further wells should be drilled. An improved understanding of the value for different drilling strategies was gained by studying distributions for in-place oil and gas volumes for various scenarios.

Introduction

Within the petroleum industry important decisions are made every day. A good decision can result in largely increased income or greatly reduced expenses.

The approach to decisions taken in this paper is based on standard Bayesian decision theory[1]. This theory is based on assigning a loss function to the different decisions, and then making a decision rule based on this loss function and the distribution of possible outcomes. The former is universal in decision theory; the latter is specifically Bayesian, since it relies on prior distributions. This decision rule tries to minimize loss in some sense, the simplest being just minimizing the expected loss.

Complicated problems and large degree of uncertainty are characteristic for many of the petroleum projects. The problems might be similar, but usually they differ enough to make it difficult to use results from previous decisions directly. To understand the problems and be able to use available data models are buildt, geological models, flow simulation models, cash flow models etc.

Description of uncertainty can be crucial to make the right decision. To solve such problems, statistical models are buildt. As mentioned above, the problems usually are unique. A straigt forward use of historical data and a general statistical model is rarely applicable. Knowledge about statistical modeling must be combined with the geologist or engineer's knowledge about the problem. The challenge is to identify important elements of the problem and build an uncertainty model, which can be easily handled.

To pinpoint the essential elements for a model is difficult task. Not only the characteristics of the field, but also the decisions that the model is supposed to support, must be considered. A simplified model has several benefits. It can easily be explained and thereby trusted by the partners in the project. Another benefit is speed and flexibility. Examinations of several sensitivities are important in understanding the problem at hand.

This paper presents part of the decision process for one of the partners in the development of the Alvheim field. The challenge was to turn relatively small Palaeocene structures consisting of both unproven prospects and proven oil and gas reserves into a field development with a good economic performance.

All partners in the presented field development agree that modelling the uncertainty is important for establishing a good development strategy. A complex stochastic model was built by the operator, but essential uncertainties can easily drown in a complicated modelling study. This paper describes a simplified stochastic model built using Excel and a Monte Carlo add-in to support decisions on how many and which structures to be drilled before development. It is capable of modelling the important upside potential seen in geophysical evaluations.

An improved understanding of the value of different appraisal strategies was gained by studying in-place oil and gas volumes for various scenarios. Using the model it is possible to quickly compare expected values, uncertainty ranges and other key measures for a range of scenarios.

The model is updated, as drilling information becomes available and further developed to be suitable for supporting concept selection decisions.

Decision theory

The decision to be made is where to drill the next well with three possible locations and the option of not drilling more wells. In the Bayesian decision framework, the main outcome of this decision will be reduced uncertainty in the oil (*STOOIP*) and gas (*GIIP*) volumes. Of course, the expected volumes will also change, but this is an unknown quantity until the well has been drilled. The reduction of uncertainty, on the other hand, can be computed in advance.

Let the observed oil and gas columns in the new well be denoted by $O = (O_g, O_v, i)$, and a_i denote the decision to drill at location i, i = 1,2,3. From prior knowledge and all data previously available, a volume distribution $f(V)$ is created, where $V = (STOOIP, GIIP)$. The loss function is then on the form

$$L(a,O) = k - u(f(V), f(V \mid O))$$

where k is the cost of drilling a well, and u is the value of knowing the volume distribution given O versus knowing only the original volume distribution. In this setting, the loss function for not drilling a new well is zero.

The problem now is to determine u. This is challenging, since this function must put a value on information, and especially decide whether the extra information is worth the cost of a well. One possible approach would be to look at the next stage decision, which would be what kind of development installation should be used, and see how this reduced uncertainty affected expected loss there. However, since the distribution $f(V|O)$ would be needed anyway, we chose to evaluate this before making any more progress with loss functions and decision rules. This distribution turned out to be so decisive for one of the locations that no further elaboration was needed.

The Alvheim field

The Alvheim field is located in PL203 licence in the Norwegian North Sea. The field extends into neighbouring PL088 and PL036 licences. It consists of three principal oil and gas discoveries named Kneler, Kameleon and Boa, each of which contains hydrocarbons in good quality Paleocene sandstones. A series of smaller accumulations that are not currently part of the development (Figure 1) also occur in the area.

The first discovery in the area, back in 1974, was a gas-oil accumulation in the structure called Gekko. Gekko was drilled based on interpretation of 2D seismic data to test the extension of the Heimdal field. Oil and gas were found, but not considered economical feasible to develop. A small oil accumulation, Kobra, was found in 1997 and the gas-oil accumulation in the Kameleon structure was discovered in 1998. After this, the area lay dormant until it was acquired by the current operator Marathon in 2001.

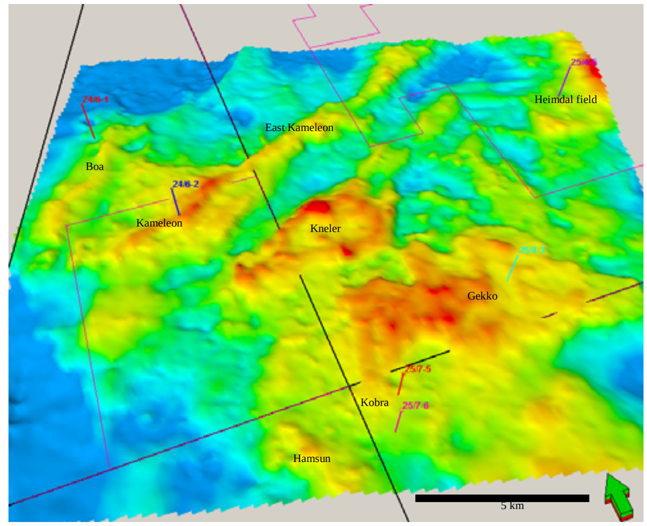

Figure 1: The Alvheim field (Boa, Kamilion and Kneler) and other structures in the PL203 area.

Exploration concepts revitalized by new technology. The Paleocene/Eocene hydrocarbon play type in the Viking Trough was considered to be exhausted in the early 80's. The use of 3D as an exploration tool revitalized this play concept and established several new promising prospects. Modern seismic data and work processes including multi-cubes, high resolution data and AVO-inversion makes a detailed interpretation of the structures possible. Still, uncertainties related to fluid content and internal reservoir stratigraphy exist.

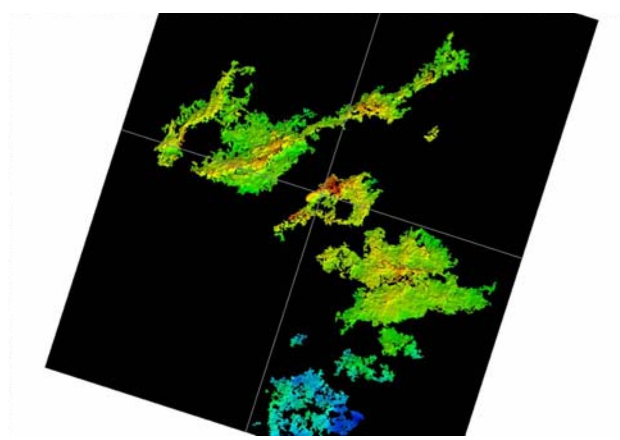

Figure 2: From left to right: Boa, Kameleon, Kneler and Gekko interpreted from seismic data.

Figure 2 shows three of the structures interpreted from seismic data. Amplitude differences can be linked to hydrocarbons, but, seismic modeling indicates a similar seismic response for oil and gas making it difficult to discriminate between the two (Figure 3).

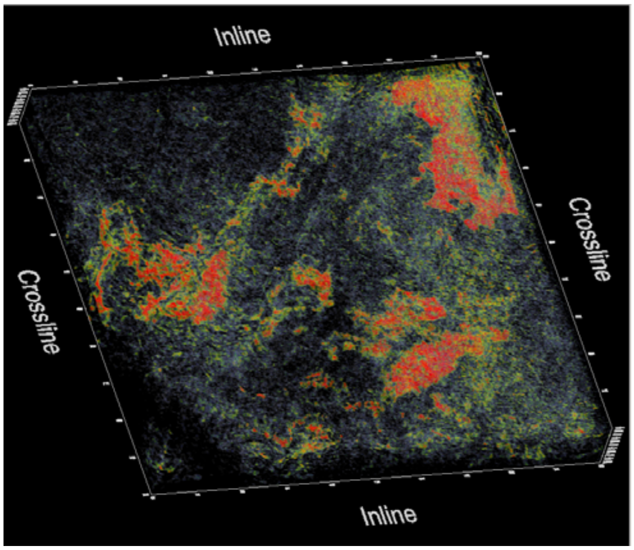

Figure 3: Seismic far offset stack amplitude rendering indicates hydrocarbon saturated structures in the Alvheim area.

Choise of development. This paper describes part of the decision process prior to the wells drilled in 2003. At this point in time much of the focus of the PL203 licensees was on the gas discoveries. The discovery well on the Gekko (1974) structure had seen 8 meters of hydrocarbons and an oil column of approximately 5 meter at structurally low position. The structure was believed to hold a significant gas volume, but the uncertainty called for an appraisial well.

The Kameleon (1998) discovery has an oil column of 17 meter below 50 meter gas, but even with a similar oil column on the nearby prospect, an oil development would be marginal or uneconomical. The Kameleon structure is a low, elongated structure 15 km long. The in-place hydrocarbon range is large. Also, there may be a connection between Boa and Kameleon.

The nearby undrilled Kneler structure is located between Kameleon and Gekko. In earlier studies this structure was expected to be gas bearing. However, as shown in Figure 4, a wide range in fluid contacts could be explained, resulting in a large in-place volume uncertainty.

Former development evaluations had favored a gas development, leaving the oil in Kameleon behind. From a wider perspective this is suboptimal. With a Kneler oil scenario in mind it was therefore important to keep both the oil and gas development options viable.

Using the model presented we were able to show *if* we should drill more structures before development and also *which* structures to be drilled first.

Stochastic model for in-place volumes

The goal for the stochastic model is a simple Monte Carlo[2] model that can be used to estimate the uncertainty in *STOOIP* and *GIIP* under different drilling strategies.The crucial step is to pinpoint the essential elements. These were believed to be,

- Fluid contact uncertainty
- Seismic uncertainty (interpretation and depth conversion)

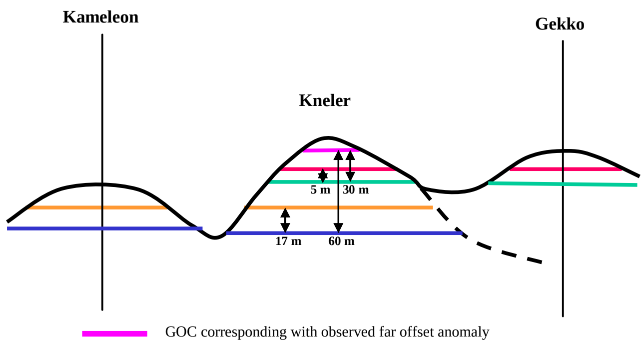

Figure 4: Possible outcomes of fluid contacts for Kneler

An exploration type of approach was selected for the modeling.

Parameterized volume depth curves. The overall geometry for each of the structures is modeled using volume depth curves. Volumes of one meter thickness as a function of depth are prepared from a geo-modeling tool and parameterized using a 3rd order polynomial, see Figure 5 for the Kneler structure.

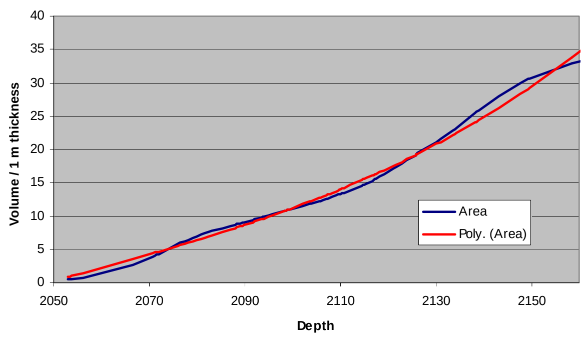

Figure 5: Areal extent vs depth for the Kneler structure.

Seismic uncertainty. The shape of the structures, given by the volume-depth functions are treated as deterministic, except from the uncertainty in overall depth of the structure (h) and an uncertainty factor (d) used to model the lateral uncertainty. The uncertainty factors are illustrated in Figure 6.

The depth uncertainty (h) is removed if the structure is drilled. The lateral uncertainty (d) will exist even if the structure has an exploration well.

Fluid contacts. In addition, the uncertainties in oil-water and gas-oil contacts are modeled. To assure consistent volumes, the contact uncertainties are linked. The oil-gas contact is drawn from a triangular (or a more general distribution) and the oil column is drawn from a distribution where the shape of the distribution depends on the oil-gas contact for some of the structures (Figure 7).

Volume model. The volume-depth functions are integrated from the oil-water contact to the gas-oil contact and from the gas-oil contact to the top of the formations to give the volume in-place. For each Monte Carlo iteration, the depths are adjusted for value of (h) before the integration and the resulting volume is multiplied with (d).

Parameters like net-to-gross, porosity, saturations, Bo and Bg were not believed to have significant impact on the current decisions and were given little focus. To get results on familiar scale (*STOOIP* and *GIIP*) they are included. Net-to-gross, porosity and Bo were drawn from normal distributions. Saturations, Bg and gas oil ratio are given without uncertainty.

The total *STOOIP* and *GIIP* for the field are found as the sum of the *STOOIP* and *GIIP* for each of the structures.

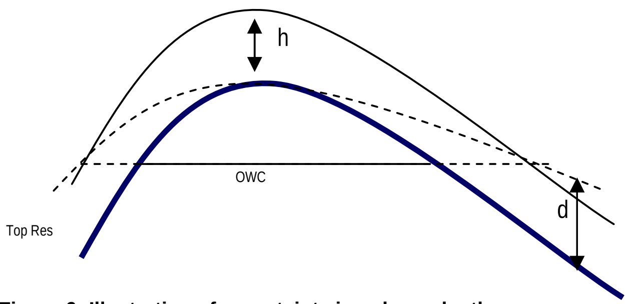

Figure 6: Illustration of uncertainty in volume depth curves.

Simulation study

Input. Studies like this, where little hard data are available directly, must rely on jugdement. The study is not trying to tell the full truth, just help the geologist and engineers to sort out their judgement in order to make the best possible decisions.

Discussions on geological interpretations were translated into uncertainties in gas-oil-contacts and oil-columns. The resulting distribution of in-place volumes could easily be examined using the model. Not surprisingly several iterations were needed to cover all the opinions around the table. Figure 7 shows the input distributions for oil-columns as they were at the end of the simulation study. Note that some of them are functions of the gas-oil contact and are presented as simulation results.

In a similar manner the input for the seismic uncertainty (h) and (d) were established from geophysical judgement and deph conversion sensitivities.

Conditional distributions. The decisions this study tries to support are, *if* and *in what sequence* additional structures should be drilled in the PL203 area.

The approach is to examine the value of different drilling strategies by studying possible scenarios of discoveries. The discovery scenarios are generated by drawing possible column observations (*O*) at the different well locations from their distributions. The oil component of the distribution is shown in Figure 7. For each drawn value, the posterior distribution *P(V|O)* is computed, so these can be compared to each other and to the current knowledge summarized in the distribution *P(V)*. The lateral uncertainty (d), the uncertainty for geological parameters (net-to-gross, porosity etc) and uncertainties for other structures still remain, so there is still a large degree of uncertainty in the conditional distributions. The simplicity of the model makes it possible to examine both the unconditional distributions as well as a serie of scenarios in the same simulation run. This makes comparing scenarios easy. Also note that the relative probability for each scenario is given as the relative likelihood for the samples of *O* used in the scenarios.

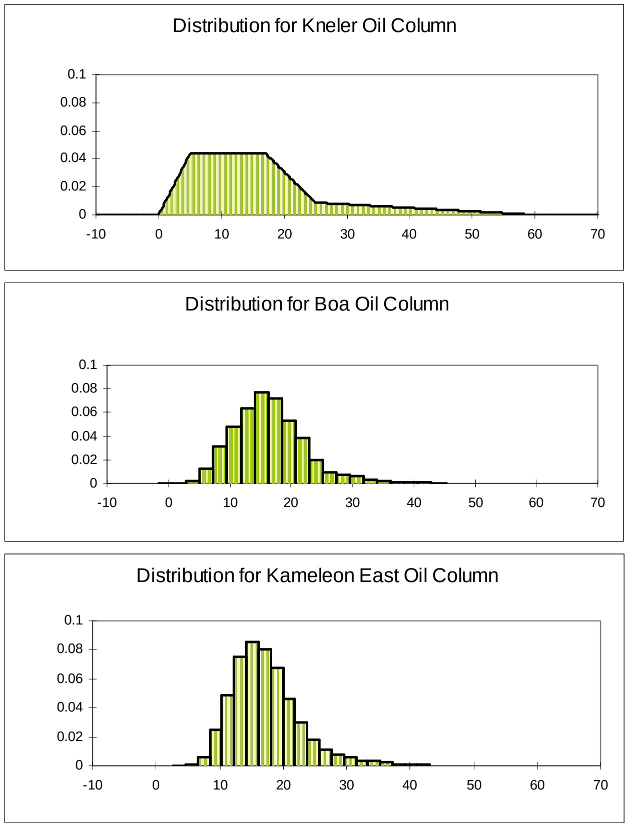

Figure 7: Oil column distributions for the Kneler, Boa and Kameleon-East structures.

Simulation Results. Figures 8 to 10 show some of the possible outcomes. The distribution without further wells, *P(V)*, is the filled area. Note that the extremes of all outcomes are bounded by this, since the uncertainties in possible outcomes are part of this distribution. Curves for different *P(V|O)* for different *O* are plotted in the same plot, with one case for each of the three well locations.

The figures show that a well penetrating the Kneler structure has a significant effect in narrowing down the total distribution for both in-place oil and in-place gas, regardless of what is seen in the well. Boa and Kameleon-East have accordingly little effect on the total hydrocarbon distributions, since the possible volumes here are much more restricted. This is partially due to the column distributions shown in Figure 7, but also largely due to the area vs depth curves and associated uncertainty.

By examining possible scenarios it was also seen that a large or small Kneler oil discovery probably would be critical to the development strategy for Alvheim due to the large effect on the expected oil and gas volumes respectively.

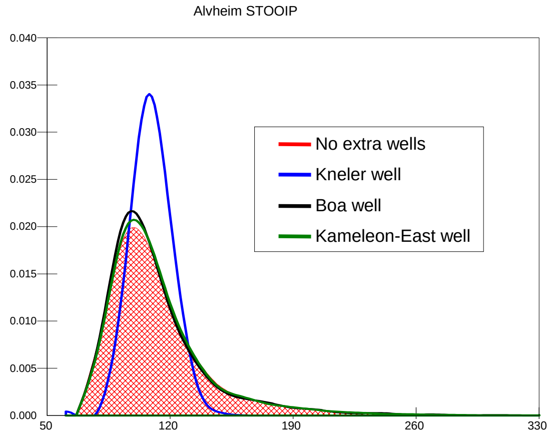

Figure 8: Effect of a discovery of expected oil column for each of the structures on STOOIP.

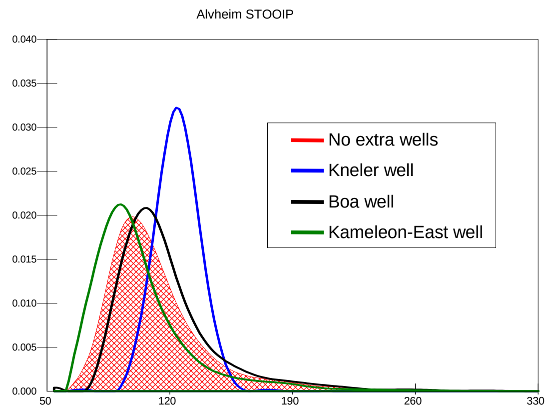

Figure 9: Effect on STOOIP for a large Kneler oil column discovery, a medium Boa oil column discovery and a small Kameleon-East oil-column discovery.

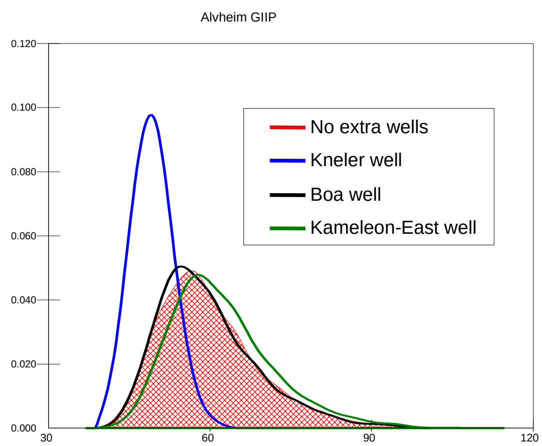

Figure 10: Effect on GIIP for the scenarios given in Figure 9.

Drilling results

Three well were drilled back-to-back in the Alvheim area during 2003. All wells revealed surprises regarding both fluid contacts and reservoir quality. What is important though, is that the results were within the ranges modeled in the stochastic model. For the Kneler structure it was extremely important that we kept the upside oil prognosis through the whole process. The Kneler oil scenario confirmed by the well turned the Alvheim development into an oil focused development.

Field development. After the successful drilling in 2003 the Alvheim field was fast tracked for development. The development will comprise an FPSO production solution, with oil exported by shuttle tanker, and gas via pipeline to the UK. 1 January 2005 net reserves have been estimated at 25 MMboe. The Development Plan was approved by the Norwegian Government in 2004 and first oil scheduled for early 2007.

Conclusions

A model well suited for the problem at hand is buildt:

- The deterministic volume-depth curves per structure provide a good basis for modeling oil/gas scenarios stochastically.

- The fluid contact and reservoir parameter distributions honour seismic and well data.

- The stochastic model of *STOOIP* and *GIIP* is hounouring most effect of drilling appraisal wells. The bulk shift top is fixed (parameter h in Figure 6), gas oil contact and oil water contact are fixed, reservoir and fluid parameter distributions are kept, and depth conversion effects away from the wells are kept (parameter d in Figure 6).

The Monte Carlo simulation study showed that Kneler oil and gas contacts are the most important factors in narrowing the total distribution of both oil and gas. Boa and East Kameleon wells have accordingly little effect on the total HC distribution.

References

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2. C.P. Robert, G. Casella, “Monte Carlo Statistical Methods”, Springer Verlag, 2005