Best Practices and Methods in Hydrocarbon Resource Estimation, Production and Emissions Forecasting, Uncertainty Evaluation, and Decision Making

R.M. Jonkman, SPE, International Oil & Gas Services Inc.; **C.F.M. Bos,** SPE, and **J.N. Breunese,** Netherlands Inst. of Applied Geoscience TNO; **D.T.K. Morgan,** SPE, Uncertainty Management Ltd.; **J.A. Spencer,** SPE, Reserves Management Ltd.; and **E. Søndenå,** SPE, Norwegian Petroleum Directorate

Summary

On behalf of a group of sponsors consisting of the Norwegian Petroleum Directorate (NPD) and most E&P companies active in Norway, a work group was established to author a report on the best practices and methods in hydrocarbon resource estimation, production and emissions forecasting, uncertainty evaluation, and decision making. The work group is part of Norway's forum for Forecasting and Uncertainty evaluatioN (FUN).

Following a detailed data acquisition and interviewing phase used to establish an inventory of the current practice of all sponsors involved, the work group postulated a relationship between a company's practices and its economic performance. A key distinguishing factor between companies is the degree to which probabilistic methods are adopted in integrated multidisciplinary processes aimed at supporting the decision-making process throughout the asset life cycle and portfolio of assets.

Companies have been ranked in terms of this degree of integration, and best practices are recommended. In many companies, a gap seems to exist between available and applied technology. Data and (aggregated) information exchange between governments and companies is also discussed. A best practice based on their respective decision-making processes is recommended.

Introduction

FUN[1] was established in 1997 and has 18 member companies, in addition to NPD. The forum is a Norwegian Continental Shelf (NCS) arena used to determine best practices and methods for hydrocarbon resource and emissions estimation, forecasting uncertainty evaluation, and decision making. It focuses on matters related to forecasting and uncertainty evaluation of future oil and gas production. Its main purpose is to optimize the interplay between the private industry and the national authorities wishing to regulate their national assets.

The basic question that began the FUN Best Practices project was whether the accuracy of Norway's historical production forecasts has been disappointing because of erroneous contributions from the companies or because of wrong aggregation by NPD. Which best practices could improve this situation? Whereas reserves form the basis for production, capital expenditures, operating expenditures, and emissions forecasting, the decision-making process in the various companies and national authorities links the various components together. Using the latest guidelines created by SPE, the World Petroleum Congresses (WPC), and the American Assn. Of Petroleum Geologists (AAPG)[2] for reserves reporting (allowing the use of probabilistic methods), the project concentrated on assessing the potential advantages of probabilistic techniques when used in combination with fully integrated asset management workflow processes.

After a discussion of the current practices of the various companies and authorities visited, best practices are formulated in the fields of estimating reserves, production, costs and emissions forecasting, decision making, planning, and communications. The paper concludes with recommendations on how to move from the current practices to the desired best practices.

Methodology of the Study

The methodology used by the FUN Best Practices Team involved a series of interviews with:

- The Norwegian Operating Units of the oil companies sponsoring the project to obtain their views on the current practices.
- The Norwegian authorities.
- The headquarters of several major oil companies to obtain their views on best practices in production and emissions forecasting and decision making.
- Government officials in other major oil- or gas-producing countries to learn from their experiences.

The interview comments were analyzed, and a set of best practices was formulated. A project currently in progress concentrates on disseminating the best practices through workshops and e-learning combined with classical training courses.

Current Practices

Reserves Estimation. All companies trading on the New York Stock Exchange (NYSE) use the U.S. Securities and Exchange Commission (SEC) reporting standards, which are encumbered with anomalies as to changes in (end-year) oil prices, novel contracts (production sharing), and a modification for North Sea fields (by exception). They are difficult to change because such changes would have consequences for financial reporting by means of the (unit of production) depreciation of capital assets by the oil companies.

Most companies adhere to the SEC rules for reporting proved reserves as a single, deterministic number. Commonly, however, probabilistic methods are used internally; only recently did a few governments start to ask for probabilistic reserves reporting from the companies. In response, SPE, WPC, and AAPG have formulated guidelines that include the option for probabilistic reserves reporting.

The standard adopted by NPD[3] relates reserves to their maturity and is, with a few minor modifications, eminently suitable to be linked with business processes, as is done internally by several oil companies. It appears that, for a number of companies, the NPD classification is not too different from the systems used internally, which are indeed linked, in some cases, to a business process. For some companies with simpler classifications, additional work will be required to comply with the NPD standards.

In **Table 1,** the various standard classifications and those used by the companies are compared.

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<table>
<tr><th colspan="24">TABLE 1—COMPARISON OF RESERVES / RESOURCE CATEGORIES</th></tr>
<tr><td colspan="2">To-date</td><td colspan="2">Developed</td><td colspan="3">Approved</td><td colspan="2">Provisional Project Sanction</td><td colspan="2">End appraisal</td><td colspan="9">To be approved</td><td colspan="4">Discovered</td></tr>
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<tr><td>A</td><td>Cumulative production</td><td colspan="3">Proved developed</td><td colspan="2">Proved undeveloped sanctioned</td><td colspan="2">Proved undeveloped unsanctioned</td><td>Nonproved probable</td><td colspan="2">Technical barrier</td><td>Nonproved probable</td><td colspan="2">Technical barrier</td><td colspan="3">Technical barrier, disposal</td><td colspan="3">Technical discovery</td><td>IR defined scope</td><td colspan="2">IR undefined scope</td></tr>
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<tr><td>M</td><td>Cumulative production</td><td colspan="2">Producing</td><td colspan="3">Sanctioned</td><td colspan="3">Development planning / reserves on hold</td><td colspan="5">Early planning phase</td><td colspan="3">Discarded</td><td colspan="3">Undecided</td><td colspan="3">Immature potential</td></tr>
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<tr><td>ERCB Alberta Energy</td><td>Cumulative production</td><td colspan="7">Established</td><td colspan="15">Future potential</td></tr>
<tr><td>Danish Energy Agency</td><td>Cumulative production</td><td colspan="3">Ongoing recovery</td><td>Approved recovery</td><td colspan="3">Planned recovery</td><td colspan="15">Possible recovery</td></tr>
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Most companies have documented the reserves categories; however, only in a few cases is the process fully described and enforced. Proved reserves are audited annually in preparation for annual reports, thereby approving reserves movements through the various reserve categories during the past period. Large companies have an internal audit and approval process, whereas medium-size and small companies tend to use external auditors.

Forecasting reserve bookings is done mainly by those companies that relate reserves to the business process. Maturing reserves becomes a key performance indicator (KPI), which can be rewarded with bonuses when certain targets are met. Some companies set "stretch targets" for this purpose; these should not be confused with forecasts.

Surprisingly few companies routinely monitor actual reserves movements against last year's targets. There is a desire to improve the reporting process, thereby minimizing data requirements.

Many companies noted that reserves tend to grow from first production onward, often after having been drastically reduced during the handover from exploration to production. Large fields tend to grow more than smaller fields, for which the upside must be established from the onset for their economic justification. This observation suggests that there is ample room for improvement of the current practices.

Production Forecasting. Only a few companies routinely compare forecasts with actual results and, in doing so, manage to improve the accuracy of the forecasts. There is some evidence that probabilistic forecasting results in higher accuracy, but the main benefit is the presentation of ranges, which can be more meaningfully related to actual performance.

During the study, government agencies outside Norway were also queried on their forecasting methods. The methodology used by the U.K. Dept. of Trade and Industry (DTI) is rather similar to the methodology used by NPD, and the percentage errors are in the same order of magnitude. The effect of the Piper Alpha disaster is notable in the sense that it affected all fields in the same way, resulting in a 15% error in the forecast.

The "world model" methodology used by the U.S. Energy Intelligence Agency (EIA) is very different from the European models. It relies on very basic information from the operators and is only successful because of the quantity of pools in the database, causing the law of large numbers to be effective. In comparison, the number of fields and operators on the NCS is much smaller, implying that more sophisticated forecasting techniques are called for.

Although sophisticated tools have been developed and reported over the years, these are not generally applied. Bias is often introduced unknowingly. Still, there is a need for more sophistication because the accuracy in production forecasting is not impressive in Norway or elsewhere (for the 1999 forecast made in 1998, the NCS operating companies had an accuracy ranging from −8 to +13 %; from 1990 to 1999, total NCS 1-year production forecast accuracy ranged from −12 to +8%). This again suggests that there is room for improvement of the current practices.

Cost Estimation. Most companies use the same commercial cost engineering software package, with only a few large companies using in-house databases. The jointly developed Standard Norwegian Offshore Cost Coding System is widely used by all companies operating on the NCS. Estimating decommissioning costs was mentioned as an area of concern.

Several companies have mandatory audits, or peer reviews, of cost estimates and find these highly beneficial. Three companies use internal benchmarking to improve the quality of the cost estimates.

Cost overruns, averaging 30%, were a major concern in all companies, but surprisingly few mentioned constant monitoring as a standard practice. The effects of edge technology, environmental standards, and scope changes were mentioned as causes for the overruns. Also, the costs associated with extending the plateau period were generally underestimated.

Some companies mentioned a linkage with KPIs, and again, stretch targets were set at times. Several interviewees recognized the danger of sacrificing flexibility to reduce costs. The cost range of one operator was felt to be too narrow and too optimistic.

Emissions Forecasting. In Norway, the driving force for emissions reporting and forecasting is compliance with the Kyoto Protocol, aiming at a 10% CO_2 reduction between 1990 and 2010. A carbon tax has been introduced as an instrument to induce the offshore industry to take measures to reduce gas usage and petroleum flaring. Despite the introduction of this tax, the actual emissions have increased because of the increased hydrocarbon production on the NCS. On a unit-of-production basis, the emissions have indeed decreased.

For the companies, the driving force is the corporate "green image," as the Kyoto Protocol applies to countries and not to companies. In some of the Norwegian operating units, there appears to be little awareness of corporate targets on emissions.

Operators report the emissions and emission forecasts annually for Resource Classes 1 through 4 (Table 1). For Resource Classes 3 and higher, NPD makes an emissions forecast with a Monte Carlo procedure. However, the results are considered of insufficient quality to influence license rounds and gas prioritizing.

Because the actual emissions are difficult to measure, they are estimated with conversion formulas based on the facilities in use in the fields and their throughput. There is a debate on the conversion factors prescribed by NPD, with some companies using their own conversion factors.

Corporate reporting of emissions generally follows corporate standards that most likely will differ from the NPD reporting.[4] The emissions reported in the companies' annual reports might therefore be inconsistent with the Norwegian data. Within the companies, there was a strong preference for emissions trading; in particular, trading with onshore Norwegian companies could be very beneficial because the most obvious emission-reducing measures offshore already had been taken.

Decision-Making Process. In this best practice study, four different methodologies were defined to describe the maturing of projects and the subsequent decision-making process.

1. Fully deterministic (base case + a few sensitivities).
2. Use of ranges in an otherwise deterministic method (e.g., producing "spider" or "tornado" plots).
3. Probabilistic approach (Monte Carlo) in the last phase of the analysis based on ranges for reserves, production behavior, and costs. The method produces expectation curves for parameters such as net present value (NPV), internal rate of return, and reserves produced.
4. Decision & Risk Analysis (D&RA; see **Fig. 1**)—a fully integrated, multidisciplinary probabilistic approach based on ranges for the base parameters in the fields of geology, reservoir properties (porosity, etc.), steel costs, manpower costs, facilities downtime, and development scenarios. D&RA also includes the propagation/aggregation of uncertainty through the various concatenated models **(Fig. 2)** and through the various decision levels **(Fig. 3).** Crucial to D&RA is a correct use of parameter, scenario, and project dependencies; these tend to have a significant impact on the eventual probability density functions (PDFs) of the KPIs. D&RA may, but does not necessarily, use detailed reservoir modeling and simulation directly. The processing of the input data also can be done by so-called fast (or reduced) models, provided that corrective measures are taken to minimize the potential bias in such models. Fast models are obviously more efficient when combined with the Monte Carlo process.

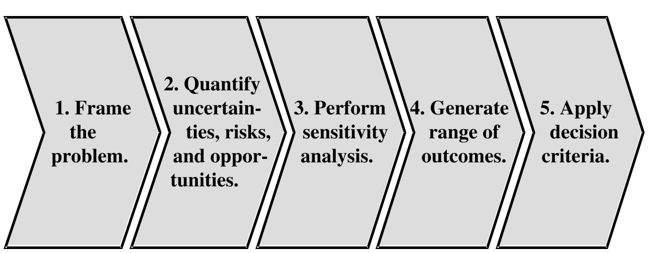

Fig. 1—D&RA process.

Based on the interviews, the companies have been classified on a scale from fully deterministic to fully probabilistic, taking both the technical capability and the management preference into consideration **(Table 2).** Table 2 presents, on a scale of 1 to 4, the degree of penetration of probabilistic methods in the various companies, both at staff and at management levels. Although most companies appear technically capable of applying probabilistic models, only a few companies use these methods routinely in their decision-making processes.

The D&RA methodology involves multidisciplinary teams and proceeds in five phases, of which the first, framing the problem, is considered the most crucial and time-consuming. Full support of management is necessary ("management pull"), as initially the method can take more time than the more conventional methodologies, and a considerable amount of staff and management training is required over an extended period. The champions of the D&RA method claim a more transparent decision-making process and significant cost savings in the development phase of the project. In practice, one finds that the *a priori* assumed probabilistic ranges appear to be too narrow. Interview techniques have been developed to improve the estimates, but a fully satisfactory solution has not yet been found. Introducing dependencies between parameters and scenarios renders the situation even more complex.

The consensus is that the oil-price uncertainty outweighs all other downside risks in the evaluation. In this context, the early production period is crucial. The reserves uncertainty causes the next most important downside. Cost overruns are the next concern; an often-heard comment was that forming an alliance with contractors has the potential to reduce this risk. Finally, the uncertainty about the rules and costs of abandonment were mentioned as a concern. On the upside, the reserves are considered to be the most important factor, immediately followed by the oil price. The decisions made in the government are of a very different nature compared to those of the companies. Important government decisions relating to a particular field are license granting, approval of a plan for development and operation (PDO), and abandonment approval. Other decisions are made at a national level, with the timing of license rounds, target setting (e.g., for emissions), gas marketing, and state participation as examples. For all these decisions, reliable information is required; to a large extent, this must come from the companies.

Planning and Ranking. In larger companies, the corporate planning process absorbs data from the operating units on expenditure and production for the developments under way and the producing fields. To these relatively hard data, the sums of the phased forecasts of the various projects (for which a development decision is still pending) are added. This aggregate production profile is compared with the long-term production target set by management **(Fig. 4).** The gap between the aggregate and the target is to be filled with production from field extensions, discoveries, or acquisitions. This type of analysis shows whether the target is realistic and allows an estimate to be made for the required resources.

To rank the project portfolio, knowledge of the corporate constraints is a prerequisite. If the availability of investment money is the constraint, then the projects need to be ranked by their Value/Investment Ratio (VIR). If production is physically (pipeline) or politically (OPEC) limited, then the unit NPV is the appropriate ranking parameter. Such ranking provides guidance for the phasing of the projects in the company's portfolio.

Although the fill-the-gap approach also could be used by the government, the process will run along different lines because the authorities have to rely on information supplied by the companies while they have no direct influence on the decisions taken in the companies. Also, the constraints and the targets of the authorities are generally different.

The constraints in Norway are the committed gas-demand profile and the stability of the supply-industry workload. The objec-

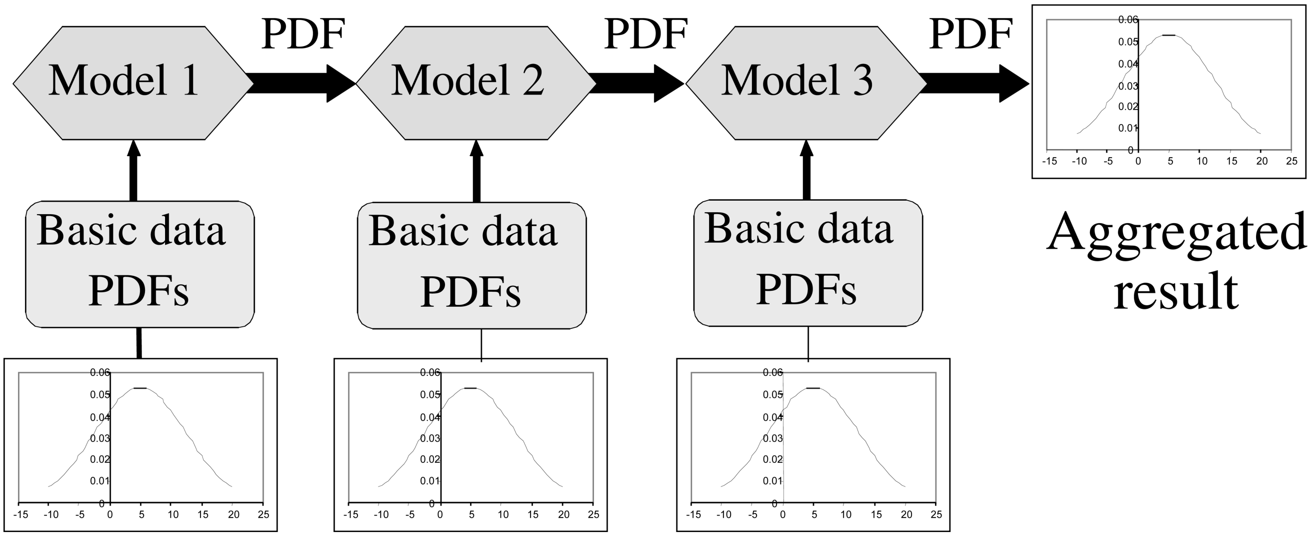

Fig. 2—Information aggregation process along the various models.

tive is to secure adequate long-term cashflow for the Norwegian economy as a whole. The decisions made by the government currently relate to the introduction of new legislation, the timing of future license rounds, the approval of the PDOs, and the allocation of gas supply to the various operators. Using these instruments, the government strives to optimize the offshore industry.

Information Flow Between Companies and Governments. Within companies, the Value of Information (VoI) concept is applied more and more frequently to contain the ever-growing quest for more data. This is done at all levels, from drilling a well to optimizing an asset to optimizing a portfolio. The VoI concept ascertains that the information potentially impacts the decision-making process and quantifies the effects of partial and/or inaccurate information.

The information needs of the government do not have the sole purpose of supporting the decision-making process; they also serve to inform politicians, provide material to attract foreign investors in Norway, and inform the general public. This makes the application of the VoI concept more difficult.

In many oil-producing countries, the government is entitled to all raw data collected by the companies (including seismic, logs, cores, and production). Central data stores provide access to governments or partners that are entitled to these data. In North America, these catalogued data stores give rise to extensive data trade between companies. In the U.K., such data stores have been set up as an industry initiative, and in Norway, NPD has taken the initiative.

In Norway, three types of data flow can be distinguished:

1. Raw data–the DISKOS data-storage initiative (managed by NPD) is designed to reduce opex and result in more effective exploration programs. The data are kept under embargo for 2 years, after which they are open to interested parties, thus stimulating the interest for the NCS. Companies complained about the high quality-control requirements of the submission, resulting in additional costs for the industry.

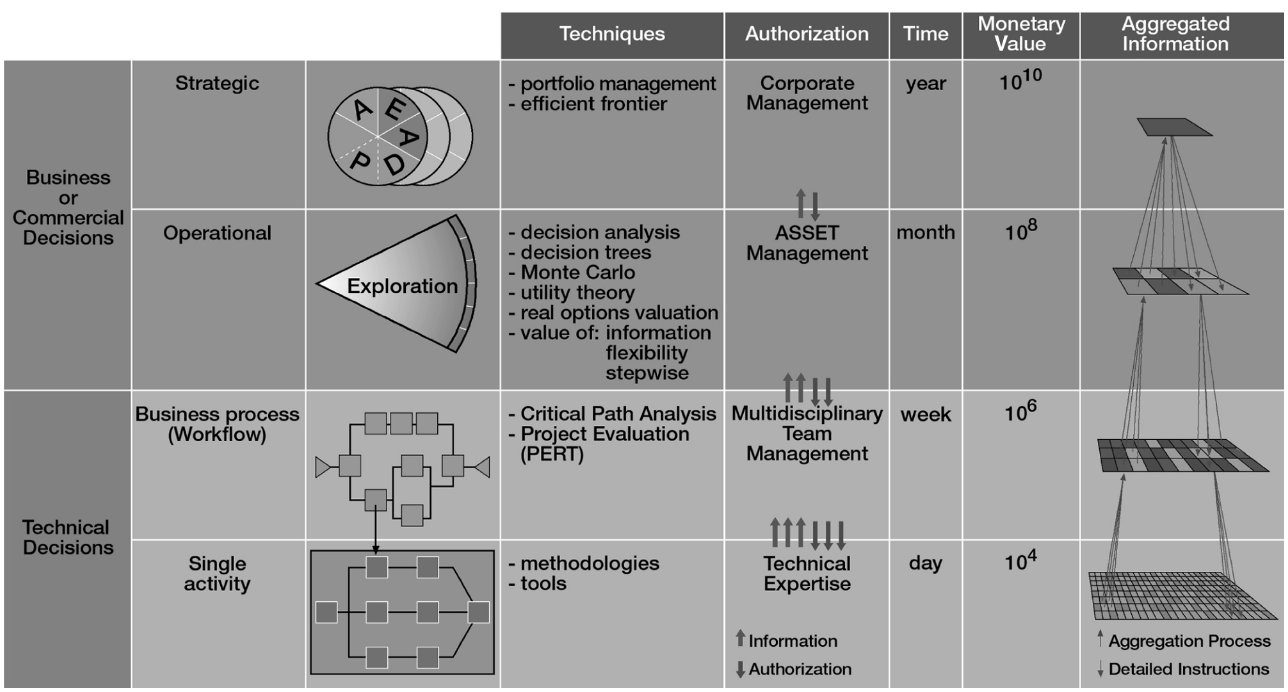

Fig. 3—Information aggregation process along the various decision levels.[5]

TABLE 2—CLASSIFICATION OF FUN BEST PRACTICE PROJECT SPONSORS

Company	Staff Capability	Management Preference	Ranking
C	4	4	8
A	4	4	8
G	4	2	6
D	3.5	2.5	6
R	3	2.5	5.5
E	3	2	5
I	3	2	5
K	3	2	5
J	2	2	4
F	2	2	4
Q	3	1	4
H	3	1	4
N	2	1	3
B	2	1	3

Note: Scale ranges from fully deterministic (1) to fully probabilistic (4); sponsors have been made anonymous.

2. Production data, expenses, and environmental data are submitted electronically to a common data storage, ensuring that the same information is passed on to operators, authorities, and partners.

3. To fulfill the government's information requirements, the companies annually supply a large amount of often probabilistic information on the various reserve categories to NPD. These reporting requirements are considered a burden if the requested data formats deviate from the internal company standards.

In North America, the authorities are more restrained in their desire for more information from the companies. The Paper Burden Act in the U.S.A. is the legal basis for these restrictions. In Canada, the information flow from the companies to the authorities is more restricted than in Norway; only well data, and not seismic data, were available to the government. The challenge is to find a balance between these extremes.

Recently, NPD started publishing reports describing trends within the industry. The information can be used by the companies to assess the timing of PDOs and other matters. Also, the government informs the companies of the anticipated capex on the NCS through seminars and meetings. This information could serve to mitigate the effects of peaks and troughs on the workload of the supply yards, thus allowing more efficient project planning.

Best Practices

It is clearly a challenge to present best practices that are best for all parties concerned. The companies visited had current practices varying all over the spectrum, and most of them were rather content with their practices. The team, therefore, postulated that there should be a relation between practices and KPIs, with the best practices resulting in the best economic performance.

On the basis of an economic benchmarking study of the major oil companies listed on the NYSE,[6] the Best Practice team inferred a relationship between corporate performance and working practices. Companies that integrated their workflow and used D&RA saw their performance improve shortly after the introduction of this methodology **(Fig. 5).** The two indicated top-ranking companies were the ones that had exhibited a quantum difference in management pull compared to the other companies surveyed (Table 2). These two companies believed strongly in a formalized, companywide D&RA process to add value to their bottom line.

With the nearly unlimited amount of variables that influence a company's performance, finding an objective, irrefutable relationship is hardly possible, however. Because of such difficulties, the team also included the findings of other recent studies that had observed a similar relationship between company performance and sophistication in the decision-making process.[7] With such circumstantial evidence, D&RA was selected as a best practice.

In addition to this best practice, the following detailed best practices are recommended.

Best Practices for Reserves Estimation.

- The reserves classification system should be linked to the business processes.
- KPIs should be used as business drivers to deliver the reserves targets for the year.
- Proved reserves can be calculated meaningfully by deterministic methods, although probabilistic methods are still preferred.
- Deterministic methods are not to be used in situations with higher uncertainty ranges.
- A comprehensive company manual should describe the reserves classification system and the reporting process.
- Peer reviews should be a regular feature in the case of material reserves changes.
- When sampling reservoir parameter distributions, spatial correlations must be taken into account.[8]

Best Practices for Production Forecasting.

- The models used for production forecasting should be as transparent as possible; the assumptions in a forecast should be documented.
- The forecast should recognize the uncertainty as given by past forecasting performance; the forecast must be checked against actual performance.
- Incorporate the timing of events in the set of probabilistic parameters.
- The forecast must involve all disciplines that may affect the outcome.
- Treat history matching of reservoir simulation models as a statistical problem. Use it to further condition the number of constrained realizations based on static information alone.
- An audit process should check the adequacy and consistency of the methods used in forecasting.

Best Practices for Cost Estimation.

- Do not sacrifice flexibility just to reduce costs; include real options valuation (ROV).
- Distinguish cost increases, which are related to scope changes generating incremental benefits, from other cost overruns.
- To ensure proper ranking of projects, a common basis for cost estimations is required; this also applies at the national level.

Best Practices for Emissions Reporting and Forecasting.
This subject is still too immature to formulate best practices that can be agreed upon internationally. For the future, the following points could be considered:

- Solve technical issues related to measuring, accounting, and reporting emissions.
- Develop a methodology for emissions forecasting.
- Integrate emissions forecasting in project evaluations.
- The policy and the function of the regulatory instruments should be communicated clearly.
- The potential of emissions trading should be explored.

Best Practices for the Decision-Making Process.

- Integrated, multidisciplinary D&RA methods are recommended, particularly for more complex projects.
- Concentrate on framing the problem, and then identify those parameters having a first-order impact on the value of the project. This will simplify the decision tree and reduce the effort required ("pruning the tree").
- Take advantage of uncertainties by introducing the Real Options concept ("make uncertainty your friend").

Best Practices for Planning and Ranking.

- "Gap analysis" on the national resource base (Fig. 4) can best be done by the government making the pertinent decisions (i.e., timing of exploration rounds and PDO approval).

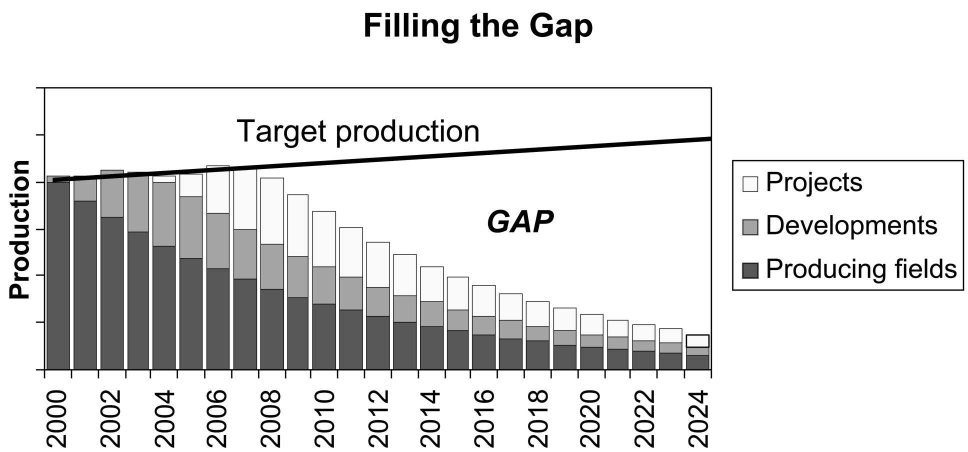

Fig. 4—Corporate planning process.

- Phasing of new developments (PDO approval) can only be done meaningfully by the authorities with due regard to the interests of the license holder.
- Maturing reserves are best left to the license holders who put their financial resources at risk.
- Optimization of approved field developments can best be done by the operator.

Best Practices for Information Exchange Between Authorities and Companies.

- Information exchange between regulatory authorities and companies should be a two-way process; both parties possess information that could improve the other party's decisions to mutual benefit.
- A long-term view on national requirements from the oil and gas sector should be published by the government, enabling the industry to optimize its planning.
- The operator should provide timely information on production deferments, cost overruns, and scope changes for national budgeting purposes.
- Forecasted activity levels at the supplier yards are to be published by the government.
- The main purpose of information gathering should be to enable decision making. Therefore, governments should be restrained when requesting information that is not regarded as beneficial to the companies: ("No value? No cost!").
- To minimize systematic errors, authorities should be cautious when aggregating data from different sources. If the information supplied by the companies has been processed according to disparate methods, governments may consider processing the information as from a lower aggregation level.
- Raw data trade between companies should be encouraged.

From Current to Best Practices

Dissemination of New Technology. Strangely enough, there appear to be a multitude of R&D products available that are not being used in most of the interviewed companies. The conservative attitude in the E&P industry may be related to:

- Lack of specialized human resources post-reorganization.
- Insufficient appreciation of the value of the new technology.
- Poor marketing by the technology providers.

This observation suggests that the transition from current to best practices could gain significantly from dissemination of and training in new technologies. Examples of such technologies are:

D&RA. This technology has reached an advanced stage, which allows its use as a standard evaluation and decision-making tool. The approach has the potential to reduce the bias in the assumptions and in the processing of the data; it also gives an insight into the range of possible outcomes and identifies opportunities for improving the project by reducing the downside risk and chasing the upside.

Decision Tree Analysis. This methodology has been around for many years, but only recently have user-friendly applications been developed that combine continuous probabilistic input data (i.e., PDFs of model parameters) with discrete probabilistic input data (i.e., scenario chances in a tree) and that communicate with elec-

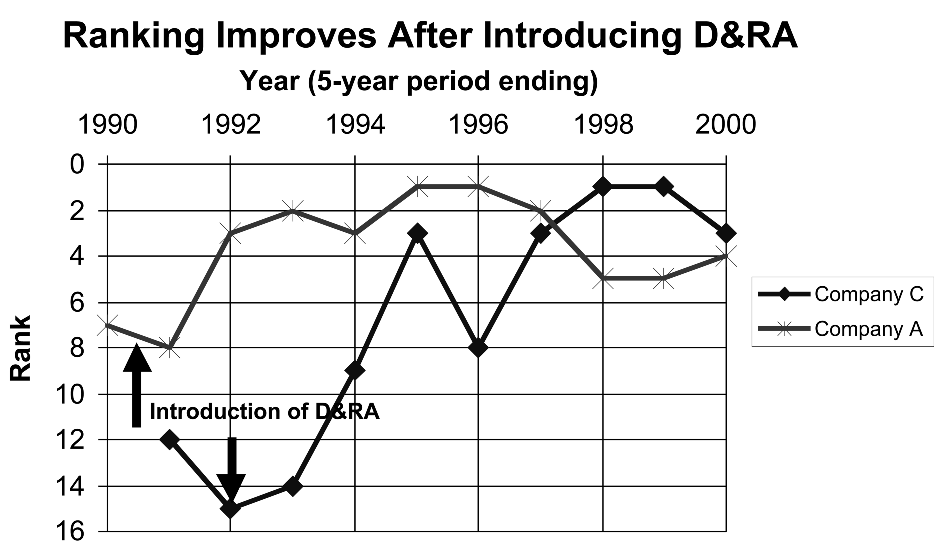

Fig. 5—Prudential Financial's benchmarking survey.[6]

tronic databases. Such applications are being used to assess the value of information and of real options.

Reservoir Modeling. Disregarding spatial correlations between reservoir properties can result in significant errors in reserves and production forecasts. Models that can handle such dependencies exist and are recommended where appropriate. Also, the traditional practice of production forecasting using history-matched reservoir simulation models has a high probability of giving biased results. Methods have been developed that produce a fully history-matched expectation curve of future production.[9]

ROV. Many companies mentioned an awareness of ROV, but there appeared to be few successful applications of the concept to date. Potentially, the method gives a valuable extension to decision trees and would allow companies to value the project upside (e.g., from the flexibility of design).

VoI. This concept has proved its value in decision making, and many companies use it to justify appraisal wells and more involved seismic processing, such as prestack depth migration. The same methodology can be used to justify gathering data for reporting purposes.

Development of New Technology. Although most of these technologies are relatively mature, there are several areas in which research and development (R&D) could render significant further benefits. Examples include:

D&RA. This methodology still has some weak areas that could be improved by further R&D. In particular, there is room for improvement in the first stage, framing the problem (e.g., by guiding the user when selecting the most appropriate models, and when setting up the decision tree). Estimating *a priori* probability distributions, including parameter and scenario dependencies, and better inversion techniques within a formal statistical framework are further topics to be researched. Minimizing bias (i.e., systematic errors) when propagating quantified uncertainties through the various concatenated models is another area of concern.

Fast Models. Research is ongoing on fast models, based on simplified physics and input data. The results give a first impression of the physical response and the economic viability of the field. Because the results are potentially biased, more research is required to understand the limitations of these models. Calibration of such fast models to comprehensive full-physics models, given certain objectives and constraints, is a way of resolving this.

Software. A software environment for decision making under uncertainty, integrated in a comprehensive workflow management system, is a clear challenge. Some initial tools already exist and could serve as state-of-the-art. An outline of such a system is depicted in **Fig. 6.** It would consist of, for example:

• *Databases,* including proprietary databases and public-domain databases, which could be accessed through the Internet. The databases are automatically updated for raw and interpreted data. The database also features links to advanced parameterization techniques in which, for example, reservoirs can be characterized by higher-order parameters.

• *Shared Earth Model,* allowing the construction of static earth models (SEM) and dynamic earth models (DEM), from which fast models and comprehensive models can be generated easily.

• *Expert Systems,* giving suggestions on how to proceed during the workflow and which best practices to apply. These suggestions would be based on the objectives of the study or the decisions to be taken and on the results up to the point in question in the total workflow. Depending on the study's objectives and boundary conditions, the expert system could also propose values or actions for correcting the bias of certain fast and comprehensive models. It can suggest investment opportunities for an ROV study.

• An automatic *audit trail,* documenting at each node in the workflow how and why certain choices were made.

• Comparison to earlier predictions, prompting *post-mortem* studies and updating the expert systems.

• *Automated updating* of models, or at least of those with minimal human interaction.

• An *ROV module,* including VoI and Value of Flexibility.

Nontechnical Considerations. A prerequisite for the use of the recommended D&RA approach is the organization along asset teams, integrated across disciplines. This is the only way in which the workflow is better controlled and the inconsistencies between the underlying assumptions are avoided.

The transition to a fully ingrained D&RA company culture will take considerable effort and several years to come to fruition. Massive management pull is required. The potential benefits, however, are very large.

To stimulate acceptance of the D&RA approach, a familiarization of probabilistic principles is required both at management level and at staff level. Moreover, basic statistics education should be incorporated in the D&RA training courses for the members of the asset teams using the approach.

Conclusions

1. A fully probabilistic, multidisciplinary workflow according to a D&RA process influences a company's competitive position. Rigorously accounting for uncertainty and planning for multiple outcomes in development planning appears to have directly impacted the bottom line (stock performance) of at least two top-ranking companies in our survey.
2. Many technical opportunities exist to improve the current practice in hydrocarbon resource estimation, production and emissions forecasting, uncertainty evaluation, and decision making. The staff, especially the management, of many exploration and production (E&P) companies seem either unaware or uncon-

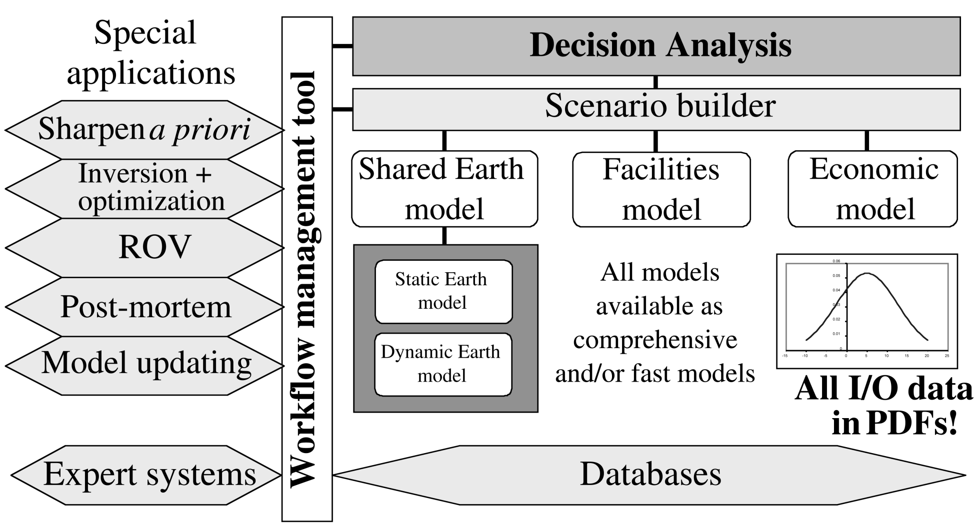

Fig. 6—Outline of integrated software system.

vinced that these techniques may affect their bottom line. Better dissemination of D&RA techniques is required.

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Rob Jonkman is an independent consultant associated with International Oil & Gas Services Inc. e-mail: jepc@wxs.nl. Following an assignment as an astrophysicist for AVCO USA and Leiden U., he joined Shell Research as a geophysicist and ended his career there as economics manager for Shell International E&P. Jonkman holds a PhD degree in physics from the U. of Leiden, The Netherlands. **Christian Bos** joined the Netherlands Organisation of Applied Scientific Research TNO in 1991 to engage in consultancy and R&D on reservoir simulation, probabilistic reserves estimation, production forecast uncertainty quantification, and decision making under uncertainty. e-mail: c.bos@nitg.tno.nl. He has 11 years of operational practice with various Shell E&P companies, where he held positions in drilling operations and in reservoir engineering. Bos holds an MS degree in petroleum engineering from Delft U. of Technology, The Netherlands. **Jaap Breunese** joined the Geological Survey of the Netherlands in 1982 (it merged with the Netherlands Organisation of Applied Scientific Research TNO in 1997). Previously, he held positions as chief petrophysicist and Head of the Resource Assessment Oil and Gas Programme, advising the Ministry of Economic Affairs on the Dutch reserves base. Breunese holds a PhD degree in physics and mathematics from the U. of Leiden, The Netherlands. **David Morgan** is an independent consultant with Uncertainty Management Ltd. Previously, he worked on a production station and as a reservoir engineer in Qatar; as a member of a UK consultancy firm writing reservoir simulators for the oil industry; as a reservoir engineer for BP; and as a Consultant Reservoir Engineer in the Technical Directorate. Morgan holds a BS degree in mathematics from London U. and an MS degree in quantum mechanics from Nottingham U. **Allan Spencer** works as an independent consultant with Reserves Management Ltd. Previously, he worked for Schlumberger as a geophysical field engineer and for BP in various petroleum engineering positions in the U.K. and overseas, including BP Reserves Coordinator. Spencer holds a BS degree in electrical engineering from Strathclyde U., Glasgow, Scotland. He served as a member (1996–99) and as Chairman of the SPE Oil and Gas Reserves Committee (1998–99). **Erik Søndenå** works for NPD in the areas of forecasting and resource assessment and national budget reporting for the petroleum sector. He also acts as project manager for the industry forum for FUN. Previously, he spent 3 years in R&D at Geco-Pracla and the U. of Bergen and 4 years as a senior reservoir engineer at Elf in Stavanger. Søndenå holds a BS degree in petroleum engineering from Stavanger U. Centre and MS and PhD degrees in reservoir physics from the U. of Bergen, Norway.