Introduction
Predicting the future and generating information on future oil and gas field behaviour is key to present and future reservoir management decision-making.

The traditional approach to predicting oil and gas field behaviour and updating reservoir models relies on a small number of scenarios (base, high and low cases) and introduces deterministic steps that do not always fit with modern reservoir management guidelines. It also means the lack of an automated workflow, making model updates time consuming.

It is with these critical aspects in mind that Emerson has developed the Big Loop workflow. A cornerstone of Emerson’s reservoir characterization and modelling workflow, the software tightly integrates static and dynamic domains and offers the propagation of uncertainties from seismic characterization through to geological modelling and simulation.

Big Loop also includes modern, ensemble-based approaches, using results from a large set of models to analyse the uncertainty in the predicted values and enabling workflow automation for easier model updates.

To effectively manage oil and gas related risks, it is essential to have uncertainty information. The evaluation of risk means having a set of possibilities each with quantified probabilities and quantified losses/gains.

The oil and gas industry has also now reached a stage where a large fraction of producing fields can provide several years of operational and production history. This includes not only production data (well data) but also seismic data that should be shared through the same models. Models that capture the reservoir uncertainties and integrate the acquired data will build more accurate predictions of the future.

Through an ensemble-based history matching workflow, uncertain inputs are identified and characterized in order to parameterize the reservoir model and give reservoir engineers the chance to constrain those parameters with the observed ‘real’ measurements.

How to estimate the probability of a hypothesis? That is the challenge reservoir engineers’ face in their daily work.

For example, if we observe the cumulative produced volumes of fields after ten years of production, what is the likelihood that the production was driven by, for instance, the aquifer’s strength?

The proxy approach
Proxies can be used to estimate simulator response as inputs are changed. This means that complex reservoir models are emulated via simpler representations leading to more cost-effective evaluations.

Figure 1 illustrates the concept of a proxy model with one parameter and one observed value. The plot shows only one uncertain parameter on the horizontal axis and the associated response on the vertical axis. The proxy is a combination of a response surface (red line) interpolating the simulation result (dots) and some Bayes Linear Estimation techniques applied on it to quantify the uncertainties between simulator responses (thin blue lines).

The reservoir engineer wants to use each measurement (or observation) to weight the simulation runs with a proxy similar to the one built. In Figure 1, an ensemble of runs is created by sampling the prior uniform distribution in blue on the uncertain parameter axis. The corresponding simulator

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1 Roxar Software Solutions, Emerson Automation Solutions
Statistically, it is not correct to select low/medium/high representative runs, but there may be runs that match the users’ criteria for low/medium/high runs in the ensemble of runs.

Percentiles can be derived from the ensemble members and their validity discussed in light of experience gained and the reliability of the probabilistic assessments. For any reservoir simulator output such as production or pressure, a range of values associated with a measure of confidence can then be calculated.

Using an ensemble of realizations clearly shows that a realization that is a P50 at a given time might well be a P90 earlier in time (Figure 2 illustrates this statement). Using ensembles can help to answer this question: How reliable is my P50 case through time? Selecting P10, P50 or P90 from an ensemble differs from selecting three runs representing P10, P50, and P90.

**Presenting ensemble-based results**

The display of uncertain data in space and time is something other industries have developed and managed to make understandable. It is up to the oil and gas sector to do the same.

Using a posterior ensemble for subsurface modelling provides a quantitative assessment of the uncertainty associated with the predictions.

The result is that spatial uncertainty maps (for example, of moveable oil – see Figure 3) can be calculated and the prediction uncertainty also calculated for any simulator output at any time. Typically seen as 2D graphs – the challenge still remains in regard to 3D models and the mapping of data.

Ensemble workflows typically require hundreds of members in order to estimate the probability density of the models.

The ability to deliver a comparative display of multiple maps to select one instance in particular for example to identify an outlier – is fundamental in regard to quality control.

Ensemble predictions contain a huge amount of information as can be seen in the oil saturation map output from the individual ensemble members on Figure 3.

How we analyse this information is key. We can plot how a well will perform with time and give an estimate of the confidence interval at any time of the time series, but added value is gained by displaying statistics in a map view. Standard response is illustrated by the blue dots, also called scoping runs.

Then, for the illustrated observation, the proxy will be improved, integrating the measurement (and its associated error) and estimating the likelihood. Figure 1 shows that there are more simulation results (green dots) closer to the best history match, i.e. where the simulator gives the closest response to the observation. This type of run, which improves the proxy, is called refinement.

Once a good agreement between the proxy and the simulator response has been found, the uncertainty parameters’ posterior distribution (in green on Figure 1) is sampled using Markov Chain Monte Carlo techniques.

Using proxies for history matching brings significant benefits. These include:

- The number of simulation runs is reduced compared to traditional AHM methods.
- The parameterization can be easily changed.
- Different and new measurement points can be added during the history matching process. This is where engineering judgment matters. The proxy-based approach strongly relies on the engineer’s knowledge of the field, and its governing behaviour.
- Finally, reservoir engineers can examine the sensitivity of results using Tornado Charts (illustrated in the example in Figure 5).

**Ensemble-based workflows for reliable predictions**

One way of predicting the field’s behaviour and estimating its uncertainty is to generate a sample of a reasonable number of runs (or realizations) that cover the range of possible updated models.

Often, P10, P90 and P50 are used to cover the space of uncertainty associated with models. However, let us take a step back and think carefully. Is there such a thing as a P50 run?
deviation, mean, and percentiles maps are very useful tools to address strategy and tactical questions across time. Emerson’s reservoir modelling software, Roxar RMS, offers the possibility to calculate and display statistics for multi-realizations.

Building integrated workflows for flexible and efficient data assimilation

The role of geophysicists, geologists and reservoir engineers is often very compartmentalized, with uncertainty captured at each stage of the modelling chain. Instead of flowing through the workflow, the uncertainty information is lost when the geophysicist delivers his ‘base case’ interpretation to the geologist, who will eventually deliver a limited number of volumetric scenarios to the reservoir engineer.

Relying on a common vision and consistent representation through shared models ensures efficient cross-disciplinary collaboration. This leads to a greater integration between reservoir modelling and simulation workflows with ensemble-based methods playing a crucial role in achieving this.

Closing the loop with Roxar Tempest and Roxar RMS

Traditionally, Emerson’s reservoir modelling software, Roxar RMS, has been used to create, edit and manage the static data required for reservoir simulation. It can on top of that, however, be a fundamental part of any assisted history matching workflow using any reservoir simulator, thereby maintaining the consistency between the geology and the dynamic data. Roxar RMS can also be used as a shared subsurface model that is continuously updated by new knowledge acquired through the field’s life.

Including Roxar RMS and its powerful geological modelling features within the reservoir simulation and the ensemble-based workflow allows the information from the dynamic data to be used to constrain the geology.

Sensitivities through proxy-based history matching show that an important part of the uncertainty is contained within the structural framework. To this end, Roxar RMS can capture this uncertainty for a better history match and better predictions.

Reservoir uncertainties are captured and varied as input parameters, creating an ensemble of realistic reservoir models that all feed into the reservoir simulator.

This leads to a better understanding of the reservoir geometry, more robust reserves estimations, and better-informed decisions for future field development scenarios.

Example of fracture reservoirs

One example of Big Loop application using the ensemble-based workflow is in calibrating a fracture network with dynamic data. This is possible with Roxar RMS operating alongside Emerson’s history matching and uncertainty estimation software, Roxar Tempest ENABLE and its simulation engine Roxar Tempest MORE.

Fractured reservoirs have become increasingly important. As fields mature, fractures will affect not only individual well production, but also sweep and total recovery rates, making them a key element in maximizing recovery and planning secondary and enhanced recovery programs. Fractures result from the deformation of the reservoir meaning that the structural uncertainty should be captured and represented as accurately as possible.
Calibrating a fracture network by history matching

History matching with Tempest ENABLE produces a proxy model. From this we can generate a statistically valid posterior ensemble.

Figure 6 shows the results of the history matching process using proxies: The blue ensemble sampled from the prior distributions illustrates the initial state of knowledge of the reservoir. The green ensemble sampled from the posterior, updated parameter distribution shows how the knowledge of the system has been increased.

During the history matching process, the knowledge of the field has been updated. For instance, Figure 6 also shows how the observations have constrained the probability posterior distribution of two parameters. To achieve a satisfactory history match, the F1 fault should be moved to the east and the most likely value of the fracture aperture for the uniform fracture set 1 is 110 μm, meaning that this fracture set should show a smaller aperture than initially thought.

Our prior, incomplete, knowledge has been updated with new information coming from the production data, and since the history match is acceptable, we can proceed to predictions, using posterior parameter distributions to sample uncertain parameters values.

A prediction ensemble, typically of 100 members, is used to derive statistics such as prediction percentiles for any result variable at any time, as illustrated in Figure 7.

Conclusions

Whether as input to field development and operational plans, investment proposals, or future divestments, the ability to accurately generate future production estimates, quantify uncertainty, and minimize financial risk is one of the industry’s greatest challenges.

Through an ensemble statistics-based approach and through the integrated Big Loop workflow, operators can achieve a greater quantification of risk and generate crucial information to support decision-making.