SPE 99828

Learnings on Sustainable Model-Based Optimisation—The Valhall Optimiser Field Trial

B. Stenhouse, BP

This paper was prepared for presentation at the 2006 SPE Intelligent Energy Conference and Exhibition held in Amsterdam, The Netherlands, 11–13 April 2006.

Abstract

Full field optimisation is a key element of BP's FIELD OF THE FUTURE technology strategy aimed at delivering a capability for remote operation and remote performance management of BP's upstream producing assets. Field of today, Valhall, is a BP operated asset in the Norwegian sector of the North Sea with a track record of applying model–based optimisation technology to support production delivery.

In 2002, Valhall identified the potential business prize from using model-based optimisation technology to support operation of the Valhall platform. The opportunity arose out of the complexity of the Valhall facilities together with the potential to optimise CO_2 emissions taxation as well as production. Initial application of this on-line, advisory optimisation technology indicated significant benefits yet, paradoxically, usage of the optimiser fell away gradually after approximately a 6 month period.

In 2004, in order to capture learnings for BP's FIELD OF THE FUTURE programme, the BP Exploration and Production Technology Group, together with the Valhall asset embarked on a field trial of the optimisation technology. The objectives of the field trial were two-fold:

- To demonstrate measurable value delivery from the optimisation technology.
- To establish the federal requirements for sustainability of the technology and associated value delivery.

Optimisation of an upstream producing asset is a cross-disciplinary process requiring close team-working and ownership of optimiser advice from all engineering disciplines, reservoir management, well performance and facilities, through to operations and commercial staff. Working with the FIELD OF THE FUTURE business process transformation team, the field trial focused on all aspects of the people, process and technology required to deliver sustainable value. The paper discusses key conclusions from the field trial and also how the learnings will influence the way forward for this technology in BP.

Introduction

Optimisation is one of the key themes of BP's FIELD OF THE FUTURE technology program. The optimisation theme is focused on the use of mechanistic reservoir, wells and facilities models to allow optimisation from reservoir through sand face to sales point. Current optimisation activities are focused on facilities and wells, to be linked eventually to reservoir to allow full system optimisation.

BP, across all business streams, has had mixed experience with the application of model-based optimisation. In refining and upstream most success has come from off-line usage of optimisation models with the operational learnings transferred to the operating plant either via enhanced operational guidelines or via advanced control schemes. In the Olefins business of the former BP Chemicals business and the current Aromatics and Acetyls business, significant success has also been achieved with closed-loop, on-line optimisation in conjunction with multi-variable control.

A common learning across all business streams has been that, for optimisation technology, as with many other technologies, the biggest single challenge to delivering sustained value is to successfully complement technology by developing appropriate business processes linked to people skills and management of change.

The Valhall asset in the Norwegian sector of the North Sea, has had an on-line, advisory optimiser in place since 2002. Initial usage of the technology generated benefits but these benefits fell away after approximately 6 months. Given the initial success of the technology, and the common theme developing within the Exploration &Production business of a difficulty in sustaining benefit from this kind of technology, a field trial was initiated with Valhall. The objectives of this field trial were two-fold:

- To assist the Valhall asset with re-establishing the benefit delivery from the technology
- To understand, for federal application, the requirements for achieving value and sustaining it. It was recognised at the outset that these requirements would embrace people, process and well as the technology itself.

It is important to state, at the outset of this paper, that the Valhall field trial is on-going and that the factors discussed here represent interim learnings that will feed BP's future strategy for this technology. This is a developing technology area and there are many additional lessons to learn, in particular those that will arise from a more effective integration of the surface and subsurface disciplines to leverage value from optimisation.

Background to the Valhall Field Trial

One of the issues to be addressed, when applying optimisation technologies to oil and gas production systems, is that of understanding how the technology fits into the different timescales of decision making. We can identify three distinct timeframes of decision making that can be supported by optimisation technology.

The first of these is concerned with optimisation of the gas and oil processing plant in conjunction with plant regulatory process control. Typically time frames here are seconds to hours. This form of optimisation is most closely analogous to the process optimisation of a refinery or chemical plant. Any process plant will possess a number of temperature and pressure set-points that can be adjusted (degrees of freedom) between upper and lower bounds to improve plant operation. Optimisation on the process can be targeted at many different objectives such as throughput increase, energy efficiency improvements, emissions minimisation, product yield improvements etc.

For most oil and gas production facilities, the number of degrees of freedom for optimisation are normally quite small and related primarily to the manipulation of plant constraints rather than the generation of additional production. However significant opportunities exist whenever there is a degree of operational complexity, when gas and oil processing plants are constrained, and when trade-offs exist, e.g. between gas throughput and gas recycle for gas-lifting of wells. With seven compression stages and an NGL recovery plant, the Valhall process topsides is fairly complex for an oil and gas processing facility (although still quite simple in comparison to the sort of process found on a refinery or chemical plant).

The second optimisation time-frame is the production optimisation of oil and gas wells against facilities constraints consistent with the current reservoir depletion strategy. BP has a very active program of off-line optimisation and decision support targeted at capturing this area of opportunity. Artificial lift optimisation, e.g. gas-lift optimisation, is normally included as part of this activity, although detailed facilities constraints are often ignored or treated very simplistically. Production plans developed and supported by this optimisation process are normally updated on approximately a weekly basis. Hence decision support in this optimisation mode is captured on time-frames of days to weeks.

Finally there is optimisation of reservoir management decisions. Whereas process and production optimisation are primarily focused on maximising production today, reservoir management is focused on maximising hydrocarbon reserves recovery and, in terms of protecting future reserves recovery, defining the boundaries for the short term exploitation of the hydrocarbon resource – i.e. putting limits on how hard process and production optimisation are allowed to push the system. Decision time-frames for this activity are typically weeks to months. However it is critical that the reservoir management constraints that limit the shorter tem process and production optimisation activities are continuously updated.

Another aspect of optimisation in support of reservoir management relates to the value of gas and water injection. This can either be as a simple pressure support mechanism or as part of an enhanced oil recovery procedure. Either way there is reserves value from injecting the correct amounts of gas and water into the best locations of the reservoir. Injection optimisation can normally be effectively de-coupled into two activities. Firstly, with the use of a full field reservoir model, understanding the of value injection to each area of the reservoir. Secondly, knowing the value of injection volumes to each area of the reservoir, optimising the performance of the available water and/or gas injection system.

For Valhall, as with most BP assets, there is significant value potential from applying optimisation to all of the above areas. Valhall is however unique in the BP group by virtue of having had optimisation technology in place since 2002. The technology is primarily focused on the first opportunity area discussed above, process optimisation, in particular maximising capacity of the topsides gas processing plant. After deliver of this technology in 2002, Valhall reported initial benefits. However use of the technology fell away over a 6 month to one year period and the technology never became established as part of the operational decision making toolkit. Given the level of the reported benefits this was surprising although consistent with other BP experience of similar technology applications - initial promise and value creation not being sustained.

The problems associated with sustaining value from optimisation are similar to those associated with the roll-out of any new piece of technology. Given the typical complexity of the application it will generally be a challenging project to deliver the technology in full. Hence attention tends to focus on this delivery phase of the project and insufficient thought is put into the implementation phase and longer term support of the technology. Once commissioned, there will be a need to periodically reassure the asset leadership team that the optimisation technology is generating real benefits and creating value when compared with alternative well-proven non-model-based approaches.

Potentially, the introduction of an optimiser will require some organisational change to ensure that full value is obtained from the technology. Organisational change is not normally driven by a need to embrace technology, but it remains very likely that the sustainability of the optimiser will be increased when the organisational focus is aligned with the technology focus.

Field Trial Scope of Work

The Valhall field trial was conducted with two activity threads, the first addressing technology, and the second addressing people and process. These two threads are discussed separately below:

Technology Thread

Overview

At the start of the field trial Valhall had been in possession of optimization technology for a number of years. The Valhall Optimiser was an on-line, advisory optimiser focused primarily on process optimisation opportunities. Referring to the process schematic shown in Figure 1, the primary optimisation degrees of freedom are the set point pressures of the HP and MP separators, the compression train inter-stage pressures, together with the operation of the stabiliser column which influences the efficiency of NGL recovery from gas into oil.

Since HP separator pressure directly influences the performance of production wells feeding the facility, the optimiser included a fixed relationship to allow it to evaluate the value of increased production gained by lowering HP separator pressure.

The on-line application comprised a number of simulation models together with an executive responsible for populating the models with plant data, scheduling model parameter estimation activities and optimisation. Results presentation was via a separate historian located on the optimiser server.

At the beginning of 2005, the Valhall optimiser technology was still available on-line but was largely ignored by the asset's optimisation process. It is worth noting at this point, however, that the on-line model was still routinely used by the operational support teams to provide insights onto operational problems and to under-pin other model-based operational and de-bottlenecking studies. This suggests that the on-line model was fulfilling a wider asset value than its immediate focus of on-line optimisation. We will return to this theme later.

Initial discussions with the asset highlighted that there were several concerns with the fidelity of the optimiser model and hence the validity of the optimisation advice. Although the primary focus of the field trial was on sustainability rather than the technology it was immediately clear that improvements to the optimizer model fidelity were required if the optimiser was to become an accepted part of the operational decision making process. Hence a technology upgrade thread to the field trial was initiated to address the concerns raised by the asset team around the validity of optimiser advice.

It is useful, at this point, to distinguish between model fidelity (the model on which the optimizer acts) and the optimizer technology itself. The original optimizer technology has remained more or less the same throughout the field trial but extensive work has been done to improve the model fidelity – the model's ability to represent the process plant. As the field trial progressed it has become clear that there are additional issues related to the optimiser technology itself that influence performance, user perception of the technology and hence sustainability. However these were not the focus of the technology upgrade which mainly concentrated on the ability of the optimizer model to represent the actual process.

The scope of the technology upgrade thread was defined by a series of interviews with key asset personnel. Interestingly (and reassuringly) the same technology issues also emerged naturally within the people-process workshops described in the following section of this paper - in retrospect the technology thread could have been fully defined as one outcome from the initial people-process workshop.

Although the requirements of the technology to address user concerns was scoped in detail, it is fair to state that the difficulty of completing the technical upgrade work was significantly underestimated and hence the work took much longer to complete than expected. Some of the difficulty encountered is outside the scope of this paper but learnings relevant to the discussion are brought out in the individual sections of the technology thread scope of work.

Establishing the correct commercial criteria

The Valhall optimizer has a complex commercial function which recognizes the product values of oil, gas and NGL together with CO_2 taxation (emissions) and transportation fees. The commercial function used by the optimizer was reviewed extensively with the Valhall operations and commercial teams. Some minor bugs in the objective function setup were discovered but it was established as otherwise still valid for current operation. A key user-input to the optimiser lies in the value assigned to NGLs and a valuable outcome from the optimiser review process was an increased clarity within the asset of the relative value of recovering additional NGL liquids into the oil product versus maximizing NGLs into the export gas stream.

Another outcome of this review process was recognition of the value of off-line use of the optimiser to study two-train operation. The Valhall process has two separation and compression trains but currently Valhall operate only one train. Although this limits capacity it provides assurance on plant availability by virtue of the spare second train. At projected higher asset oil and gas rates during 2006 and 2007 two train operation is likely to be required providing improved instantaneous capacity but potentially lower availability without a spare train to back up operation. Although the optimiser technology cannot answer this throughput versus availability question directly, the commercial team could see that it can contribute to a much better analysis of the right throughput to justify two train operation.

Validating optimiser constraints

The Optimiser's minimum and maximum limits on variables and the upper and lower bounds on constraints was reviewed and agreed with the asset team. It was important to ensure the operations team were happy with these parameters and would take long term ownership of their value. The impact of these parameters is to ensure that the optimizer does not recommend operational set-points outside of the limits with which the operations team are comfortable.

Definition of optimiser variables (degrees of freedom)
As for constraints, a similar review was held looking at optimiser variables. It was clear, from discussion with the Valhall sub-surface team, that the HP separator pressure variable, as implemented in the original optimiser technology, was not a suitable variable for optimisation over short time frame. Many of the wells were too sensitive to tolerate continuous adjustments to the HP separator pressure. Separator pressure adjustments could only be made with extensive consultation over degree and rate of change with subsurface engineers, a part of the longer term production optimisation process. There was however still value in knowing that, from a topsides perspective, an HP separator pressure reduction was possible. This could then be included in the subsurface production optimisation plans.

To accommodate the short term process optimisation and longer term production optimisation perspectives, it was decided to reconfigure the Valhall optimiser to include two optimisers, one varying HP separator, the other keeping HP separator pressure fixed. The two optimiser could be accommodated running in parallel on a 4 processor architecture server provided by the Valhall asset.

Additional work was also done to improve the optimizers understanding of field deliverability as a function of HP separator pressure. This is described in a later section.

Enhancing Optimiser Output
A key aspect that Valhall had struggled with, when using the optimiser, was being able to understand the rational behind the recommendations. Set point recommendations normally involve a morning meeting conversation between onshore and offshore teams. When a change is requested it is useful to be able to back this up with an explanation for the change. Any change also involves risk and it is important to be able to assess this risk against the benefit of the change.

To assist the interpretation of optimiser advice, the output from the on-line optimiser to the results historian was increased to include the different elements of the commercial function broken out separately in the optimiser results data base to allow the separate contributions to be visualised.

It was, however, recognized that simplifying Optimiser results interpretation was not a trivial issue to resolve and that the solution was unlikely to be provided simply by increasing the degree of stored output. It was an important area that would be assessed more fully once the revised technology was up and running and in use.

Using up to date well models
The original Valhall Optimiser used a simple, fixed, flow versus pressure relationship to advise the optimiser on the value of lowering HP separator pressure. The relationship was not updated by the on-line system. A gas make-up stream with variable flowrate but fixed composition was used by the online system to ensure the model was in correct material balance as indicated by the oil and gas fiscal meters.

To improve the optimiser's representation of field deliverability it was decided to upgrade the optimiser to include a representation of the hydraulic performance of each Valhall and Hod well. This was seen as advantageous for a number of reasons:

- If the well models were continuously updated against well test data, the optimizers prediction of the field flow versus HP pressure relationship would be more accurate based on the summed hydraulic performance of the individual wells.
- Having the optimiser hydraulic relationship based on the assets well performance models would increase confidence within the subsurface community of the validity of the optimiser predictions
- Although not used directly as optimiser degrees of freedom, having individual wells represented in the model would facilitate future off-line studies looking at well performance optimisation against facilities constraints.
- The individual well models running in the on-line environment could be used to infer non-measured well parameters such as oil, gas and water rates together with predicted down-hole pressures. This was identified as being very beneficial by the asset's sub-surface community. Looking to the future, the BP subsurface project ISIS is planned to be rolled out at Valhall. The primary focus of ISIS is model based inference of the down-hole flowing conditions in each well. When in place, this technology will provide the Valhall optimiser with a much more complete picture of what is happening in real-time on each well.

Given that the Valhall optimiser typically optimizes in approximately 15 minutes, it was not feasible to run the BP well models dynamically for each well inside the optimiser. Rather an Excel interface was develop to allow well head performance relationships to be developed for each well and passed to the on-line optimiser in the form of validated well head performance correlations. The impact of gas-lift on each well was represented in a similar way via an extension to the performance relationship equations.

The Excel interface between well models and the optimiser was also set up to allow individual well performance relationships to be rate-tuned against current well test performance prior to entry into the optimiser. This was felt necessary in case the frequency of well model updates (an off-line activity) did not meet the requirements of the on-line system.
A late addition to the on-line optimiser's capability in this area was to allow well status (flowing or not flowing) to be automatically detected by the optimiser executive and passed through to the on-line model.

Improving the reservoir fluid representation

A significant optimisation opportunity on the Valhall topsides process lies in understanding the value of NGLs recovered as liquid (in the oil product) versus left in the export gas product. The Norwegian CO_2 taxation burden is also very sensitive to the NGL content of the lean and rich fuel gas streams used by Valhall for power generation and process heating using a circulating hot oil system.

However, NGL contributes only around 5-10% of the overall liquids production of the Valhall and Hod fields. Hence optimisation of the NGL recovery process relies on an accurate compositional model of the overall reservoir fluid being processed such that the NGL proportion is correctly predicted. This form of compositional model for the combined processed reservoir fluid is not readily available on most assets – online measurements typically consist of overall gas and oil flow measurements together with well head pressures on each well. Well performance models that could support the optimiser frequently use black-oil fluid models with limited compositional information. The original Valhall optimiser used a fixed full-field fluid composition. The weaknesses of this approach was highlighted by the typically poor match to plant NGL yield, an area of uncertainty that cast doubt on the operational set point changes recommended to improve NGL recovery.

In practice, the Valhall subsurface community maintains a database of fluid PVT data for six samples taken across the Valhall and Hod reservoirs. Based on this they have mapped the Valhall and Hod reservoirs into six compositional regions. With the PVT analyses, a common fluid characterization (pure plus hypothetical components) was developed for all reservoir regions together with a fluid composition representing each of the 6 regions.

Together with a mapping of wells onto reservoir producing horizons, as shown in Figure 2, this compositional information could be used to assign a base fluid composition to each producing well in the optimiser model. Using the rate from each well an improved estimate of the overall field fluid composition can be established. The compositional model can be further improved by locally adjusting the fluid composition for each well to match the most recent well test GOR and water cut information. The GOR compositional adjustment can be performed by simulating and matching the well test procedure and allowing equilibrium free gas to be adjusted to match the observed GOR.

The Excel interface developed for the well models was extended to allow base compositions to be assigned to each well and the GOR and water cut compositional adjustments to be calculated and fed to the on-line optimiser.

Increasing topsides model fidelity

A number of improvements to the topsides model fidelity were made to increase operations confidence in the optimiser advice. Some of the key areas addressed were:

- Representation of the plant fuel gas balance including lean and rich gas power generation and hot oil loop heating.
- Hydraulic limitations in the liquid line from the HP separator to the MP separator
- The validity and representation of the individual compressor constraints
- The representation of the stabilizer and reboiler

A fundamental problem with the Valhall optimisation architecture was encountered here. The full on-line optimisation capability involved:

- Parameter estimation of equipment performance, e.g. compressor actual head and efficiency, based on comparison between model data and plant data.
- Simulation of current operation, using the latest estimated equipment performance parameters
- Optimisation using the latest parameters

To deliver this capability the optimiser uses a number of models rather than a single model of the plant. For any single plant representation update, the modification has to be made in at least 3 simulation models, firstly one involved in parameter estimation, secondly one involved in plant simulation, thirdly one involved in optimisation. This is a significant maintenance overhead that complicates the management of change process that needs to be carried out to sustain the technology. For Valhall, validating the changes in all 3 model locations is also very difficult. Overall the complexity of the model architecture has a clear impact on sustainability. What is suggested here is a single plant model that can be used for each of the activities listed above.

Analysing the Optimisation Business Process

With the optimiser technical upgrade thread defined and underway, a number of cross-disciplinary workshops were held with the Valhall asset team during 2004 and 2005 to map out the business process of optimsation. The workshops and subsequent analysis were led by BP's Field of the Future team using the MooD methodology [Newman 1996]. The main workshops were supplemented by smaller focused group sessions at which the process map was refined and fine-tuned. Inputs from similar workshops at other assets (notably Shiehallion and Central Azeri fields) were also incorporated.

The focus of the analysis was on defining the overall production optimisation process with the role of optimisation technology allowed to develop naturally. The results of this analysis can be summarized by the diagram shown in Figure 3. The process diagram is complex but, not unexpectedly, follows a fairly conventional Plan-Do-Measure-Learn methodology focused on maximizing production. Each box on the picture represents an activity which needs to occur for the overall process to function correctly (be sustained). Each activity has an accountable owner together with measurable inputs and outputs. Each of these low-level activities was further analysed to estimate a time (elapsed and actual), necessary resources, tools used and necessary skills and competencies.

The MooD analysis highlighted some important issues. For example, the optimiser relies on valid well models in order to correctly predict the combined reservoir fluid hydraulic performance and composition. Valhall carries out well tests frequently on all wells. At the start of the MooD analysis it was thought that the appropriate well model was updated whenever the well test data was collected. In practice it emerged that the well model updates are done infrequently when a well is perceived to have a problem and further analysis is required.

In addition, although the primary focus of MooD was people and process, a key output from the early MooD analysis was an assessment by asset personnel of the necessary attributes of the optimiser technology. Reassuringly these requirements correlated very closely with the scope of work already defined by the technical upgrade thread of the field trail. One major strength of the MooD analysis workshops was that this information was collected in a much shorter time period. Overall this further analysis was very encouraging in that it suggested that the technical upgrade work defined by the field trial was addressing the right areas.

Identifying the optimisation business process for Valhall is a key step, together with clarifying the roles and competencies of the people who perform the associated activities. Focus has now switched onto which of these activities can be automated either partially or totally in order to enhance sustainability. A key focus area is the well model updating process which is very manually intensive but also relatively straightforward to automate.

A conclusion from the work so far is that new processes can only be designed to a certain level. There will be always be some tasks or activities that will need to be “solved” on the fly, probably imperfectly and then progressively refined.

Project Status and Learnings

The upgraded optimisation technology was finally accepted by the Valhall asset in December 2005 and the field trial moved into an extended operate phase. Usage and added value from the technology will continue to be gathered throughout 2006.

Within BP there is significant degree of experience with model-based optimisation projects. There are many learnings to be taken from the successes and failures of these projects, together with the wider industry experience. Many of these learnings impact sustainability. Also, it is important to recognise that the primary focus of the wider industry understanding has been on the initial delivery and validation of value rather than on sustainability. Hence, it is felt beyond the scope of this paper to present the Valhall learnings in terms of this wider context. Instead the Valhall Field Trial learnings are presented as “found” and there will undoubtedly be some overlaps and repetition of learnings gathered and reported elsewhere. In addition there are expected to be issues reported here, particular to BP, that will not be generally relevant elsewhere.

The Importance of Appropriate Technology

The primary focus of the Valhall Field trial has been on sustainability and not on technology. Hence at the start of the work the decision was made to perform some minimum upgrades to the existing optimiser application, as dictated by asset feedback, but to work with essentially the same technology as originally installed. However, in practice, the capability of the technology is obviously very important in terms of delivering value and sustaining it.

A key question to be answered is, whether or not the process in mind is suitable for the application of optimisation technology at all. This is a question that normally would be assessed at the very conception of a project as the business opportunity is evaluated and best technology solution is determined. The bottom line is that, if the wrong technology is selected, not only will value delivery be put at risk, but sustainability will be that much more difficult as technology interventions are needed more frequently.
There are a number of issues to consider in order to answer this question including:

Complexity.

A question that needs to be answered is whether the asset to be optimised is complex enough to warrant the use of an optimiser. The Valhall topsides is more complex than many BP gas and oil processing facilities. It is significantly less complex than an LNG plant or refinery. Based on the field trial experience the Valhall plant is sufficiently complex to justify optimisation but it is likely that, for most process topsides, a technology such as multi-variable control will be the most appropriate on-line optimisation technology – the number of degrees of freedom is small and the controller gains are of constant sign. When the scope of the optimisation application being considered includes well optimisation and, in particular, gas-lift optimisation, then there is certainly sufficient complexity to justify full model-based optimisation.

Stability.

The Valhall optimiser is based on a steady-state process model. Many current on-line and off-line optimisation tools, capable of application to wells and facilities, are based on steady-state simulation models. In practice the Valhall plant cannot be described as steady state. Due to slugging from the Hod wells and from the Flanks multi-phase lines, the process is subject to fluctuating oil and gas flows that generate disturbances that propagate throughout the process. Poor setup and tuning on certain control loops on the process interact and generate additional transients into the process.
For Valhall, a thorough assessment was made prior to the original optimiser implementation as to whether the project, based on a steady-state optimiser, could add value given the unsteady-nature of the plant. The conclusion was that the optimiser application was still justified – despite the noise in the process there were distinct operating points that the optimiser could predict that were measurably better than the current operating point and allowed additional throughput or NGL recovery. Experience from the field trial partially supports this conclusion – there are benefits to be obtained from the Valhall optimiser. However it also clearly shows that,

if the process disturbances could be removed or significantly reduced, there would be an additional tranche of benefit from the optimiser – currently some of the value predicted by the optimiser cannot be captured due to the variability of the plant.

In summary, good plant control underpins delivery of value from optimisation. If the plant is unstable that first attention should be on achieving good control.

Another aspect of stability that needs to be considered with integrated well and facilities optimisation is that of unstable and cyclic wells. For unstable wells, conventional models are not good at predicting the well head pressure or HP separator pressure at which the well will die. The optimiser technology will thus have difficulty representing the allowable constraint on these parameters during optimisation. For cyclic wells, it is very difficult for the asset to characterise well performance with a conventional steady-state hydraulic model based on well testing. The well performance will peak when the well is first bought on and decay rapidly until the well is shut in and rested for a period to recover.

Infrastructure.
Is the extent and quality of plant instrumentation sufficient to support optimisation? Can the current performance of the operating plant, compressors, pumps, heat exchangers etc; be sufficiently understood to enable optimisation to be performed. For wells, are well tests carried out routinely and returning valid data, how accurately is current well performance understood, are the well hydraulic models maintained and up to date.

The Value of One Model
As described earlier in this paper, the Valhall optimiser architecture is quite complex with the optimiser actually using a number of simulation models rather than a single model of the plant.

For long term sustainability, the technical assurance of model updates is very important. User confidence on the asset can be lost very quickly if the optimiser starts giving poor advice. With the Valhall system, it is quite difficult to ensure an effective technical assurance process for model updates. Even simple model alterations severely test the capabilities of a good management of change procedure given that any change has to be replicated in at least three separate simulation models. Inevitably with a system where changes have to be made in multiple places, inconsistencies tend to creep in and user confidence will be under-mined as a consequence.

Much of this difficulty and system complexity can be removed by virtue of a single-model architecture whereby the same simulation model is used for a variety of activities including data reconciliation, parameter estimation, simulation and optimisation. Most modern simulation modelling systems can support a one model architecture for optimisation although open-equation based environments are much easier to configure to meet this requirement.

A one-model architecture also supports the wider use of the optimiser model on the asset. With the Valhall optimiser it is quite difficult to take a copy of the on-line model and use it offline for simulation case-studies. This is not a criticism of the Valhall optimiser as configured. Its intent was on-line optimisation and that is what it delivers. What the field trial has shown, however, is that the asset will need to use the underlying model off-line, both to provide assurance on the optimiser advice and also to support a wide range of other off-line simulation based activity. Hence future on-line architectures need to be designed with both the on-line and off-line application in mind.

A related aspect of the one model approach and one that actively supports sustainability is that of using discipline tools of choice to deliver asset-wide optimisation applications. Most BP assets have enough difficulty maintaining one set of valid well performance models. What they most definitely do not need is an optimiser that uses another separate independent set of well performance models that will also need maintaining. Even worse, when separate models are used, the well models running in the optimiser may not agree with the models used by the subsurface engineers to manage their wells

There is, of course, more than one way of implementing optimisation built on the discipline tools of choice. For example one way is to put the discipline tools directly into the optimisation environment such that they are run automatically by the optimiser to evaluate gradient information and optimise. Another approach is to have a separate asset representation running inside the optimiser but with this optimiser model able to be configured directly from the discipline tools. Neither approach is straightforward with the BP toolkit although several of the simulation software vendors are developing modelling environments that simplify the system architecture for true integrated asset modelling. A simpler architecture will enhance user understanding, reduce maintenance costs and hence improve sustainability.

The Valhall optimiser currently uses a mixture of these approaches. The facility model is run dynamically on-line but the well models are represented as appropriate correlations derived from the off-line models. One clear learning from upgrading the Valhall model is that it is not safe to assume that a tool designed for off-line use, will work reliably in an on-line environment.

The value of a holistic view of Simulation
An optimiser, such as the Valhall optimiser, is just one application of simulation to generate value by supporting and enhancing operational decision making. An on-line optimiser also always contains within it another application of simulation – that of using an on-line model to infer non-measured parameters. This is required in order to allow the optimiser to establish a base-line of current operation (analogous to history matching for a reservoir simulation). However, it is an activity that in itself can generate value. On Valhall, from the optimiser, the engineers are able to trend efficiency and head for each compression stage over time and identify when equipment performance is changing. Additional

valuable calculations are possible from an on-line compositional model. An example of this that is being investigated for Valhall is that of a hydrate alarm. The Valhall gas-plant operates close to hydrate formation condition at key stages of the process and the on-line model, with a good knowledge of stream compositions, could be used to advise the operations team of the potential onset of a hydrate formation condition.

The model within the optimiser (when we have delivered the one-model vision) can easily be taken offline and used to do step out or what-if analysis. For Valhall there are many examples of the use of a validated off-line tool. The study of two-train operation is one mentioned earlier. Another involves studying the impact of rising gas pipeline pressure on plant capacity.

The Valhall optimiser uses a steady-state model. There are many actual and potential applications on Valhall of dynamic simulation from off-line operational support and troubleshooting, through control system analysis and tuning to Operator Training Systems (OTS). An on-line model with parameter estimation can be used to initialise the starting conditions and model parameters for such dynamic analysis, generating a more rapid operational response capability and significantly reducing manual effort setting up base case models. Conversely, a dynamic model can be used to study the best trajectory from the current operating point to the predicted optimum.

All of the above activities can add value to an asset. All can exist and take place independently although many of the synergies outlined above will be missed. From an asset leadership perspective it is important that this holistic view of simulation is understood and the synergies recognised such that a strategic approach to simulation can be assessed relative to an ad-hoc approach.

Figure 4 shows a simple slide we have used many times in BP to describe how simulation models add value. Optimisation sits at the pinnacle of this diagram, linked to better decisions. However, on the journey to optimisation (taking a holistic view), there is much value to be released in the process of turning raw data into knowledge and understanding of the asset.

For simulation and optimisation it is very true to say that the whole is far greater than the sum of the parts

Optimiser Model Credibility
The Optimiser advice must be credible to the asset operations team. The answers that the optimiser produces must be believable over a wide-range of scenarios and should be at least as good as the ones generated manually. Ideally the optimiser must tell the operator something that he/she didn't know previously and make a difference to the plant by the information that it produces. Whilst it is essential to make the optimiser as credible, reliable and usable as possible it is also important to emphasis that the technology is not perfect. By making the limitations of the system explicit, trust and credibility in the optimiser is enhanced.

When working with an optimiser, operators like consistent advice and achieving this offers some challenges for the current Valhall technology. A particular area of focus has been on ranking the impact of each variable that the optimiser is manipulating. Variables that have very low impact on the objective function, tend to move about in an apparently random manner within the optimizers recommendations, a behavior which potentially undermines the applications credibility.

Another key area is the path through which the plant must move from the current operating point to the predicted optimum. The steady-state optimizer gives the operators no help here. There is value to be obtained by moving to the new operating point but much value to be lost if the plant trips during the transition – a plant trip will negate the benefits arising from many weeks of optimization. Additionally, the new operating point may be more susceptible, than the current position, to a plant trip when a major process disturbance is encountered. To address these issues, the field trial has focused on using Valhall's high fidelity dynamic model alongside the optimizer to assess the controllability of the process both during the transition and at the new operating point. This work has proved very encouraging and the utilization of plant dynamic models to support optimizer implementation is likely to be key element of future applications. .

Optimiser Availability
The Optimiser technology needs to be reliable. The system must work and continue to work in a wide-range of circumstances, and hence exhibit high uptime. The optimisation process is a continuous one and must be consistently able to contribute to the decision making process if it is not to become quickly ignored. The necessary time required for vendor support of the technology must be low. However, the support vendor must provide the appropriate level of system support to ensure that the system evolves and user issues are quickly resolved.

Optimiser Usability
The Optimiser must be usable by the asset operations team. Ideally, the system must be intuitive in use and produce output that is easy to interpret. The system should be configurable for a wide range of inputs, outputs and objectives. It should be possible to expand the scope of the system with ease. The operator interface must be well designed from the perspective of the operator

It is fair to say that the current Valhall optimiser does not satisfy all of the above. When the value is high then the management of change issues can always be addressed. Requirements around interpretation and ease-of-use are less easy to define but critical to sustained value delivery and a key focus area for this technology moving forward.

The Handover of the Optimisation Technology
It is important that the technology is rolled-out in a gradual and well executed manner. Timing is very important here, in particular not introducing the technology too early before full

testing and validation has been carried out. By introducing the technology in a well controlled manner, potential faults are diagnosed and corrected and the overall confidence in the technology is gradually built up to a satisfactory level. This is particularly relevant in the context of Valhall where there is strong support for the optimiser amongst shore based engineers but little awareness amongst offshore engineers. Establishing a good understanding of the optimiser amongst the shore based engineers is a precursor to implementing the technology offshore.

During roll-out of the technology the software must be fully validated and procedures quickly established for the day to day use of the optimiser. These procedures will only be sustainable if they are seen to contribute to adding value.

Maintenance of the Optimiser

The technology needs to be proactively supported. Once technology has been successfully delivered and site tested, it is common for an asset to establish a minimum support agreement with the vendor for essentially reactive support. A satisfactory level of support must be provided by the vendor or service provider to ensure that all faults or problems are solved as quickly as possible. This level of support should also include upgrades to the existing technology, which will substantially enhance the predictive power of the optimiser. The overall accuracy of the results generated by the optimiser should be reviewed by the support vendor and by BP's Exploration and Production Technology Group on a quarterly basis.

Maintenance of the optimiser and ongoing development should be supported through an upgrade contract with the systems software provider, ensuring that the champion of the optimiser is notified each time a new version of the modelling software is released. Clearly a provision for the support of the optimiser and upgrade costs must be included within the asset's Opex budget. In addition to financing the necessary modifications to the optimiser, it is important that appropriate control procedures are implemented to ensure that the optimiser fully reflects the plant's state at all time. All changes to the asset should trigger a request to the optimiser's support company / department to modify the optimiser as part of that project. The selected champion for the optimisation technology should actively monitor the system's use and performance, feeding back recommendations for the continual improvement through the asset change management system to the support vendor.

Training and Development

After site acceptance of the optimiser technology, training is required on the use of the optimiser. The training program needs to cover both the use of the on-line optimiser and the planned use of the underlying models to support off-line analysis. Different end users are likely to be involved with these two aspects of training.

With training on the on-line system, the training needs to focus on how to interact quickly and efficiently with the optimiser and take advice into a morning meeting or similar conversation that can result in action and added value. Interpretation and assurance are the key descriptors here as the optimiser champion seeks to answer:

- What is the optimiser doing differently over current operation?
- How much additional value is it predicting?
- How does that additional value arise?
- How difficult will it be to implement the change, what risks are involved?
- Is the change worth making?
- Has the model/optimiser fully converged?
- How consistent is the current advice with recent history?
- How steady are the plant model tuning parameters?

These are all important questions and some of them are very difficult to answer, particularly questions concerning change and risk. With a closed loop system this interpretation and assurance would need to be built into the on-line application itself. The subject of how to do that is beyond the scope of this paper. For an offline system or an on-line advisory optimiser then human intervention is possible at this stage. The technology has the potential to be very helpful but, if not well designed to focus on answering these questions, will mostly confuse. A key focus area of future work within BP's Field of the Future program is on the visualization and interpretation of optimiser advice. Results from this will be reported at a later date.

With any new technology, but especially with optimisation technology, operator trust needs to be built up gradually by the demonstration of sound advice and measurable added value. Through greater trust, the operators will have more confidence to consider and act on the optimiser advice. A satisfactory level of operator confidence is therefore a prerequisite for sustainable optimisation as, by its very nature, the optimiser will attempt to run the process closer to its limits and consequently reduce the operator's comfort factor. One possible measure of sustainability is that the operators complain when the optimiser is taken away.

Training on the off-line use of the technology is required to support the wider use of the technology. This training will be aimed at facilities engineers in support of operational troubleshooting or plant de-bottlenecking studies. The training will be primarily on the simulation models themselves and the associated software. The simulation models need to be sufficiently open to allow the asset engineers to fully understand assumptions and limitations of the models that are relevant to the task.

Documentation

Documentation is a key element of technology sustainability in a company like BP. Assets operate for many years but the people performing tasks within the asset will change relatively frequently. Good documentation will support knowledge transfer in the management of change process as people move on and new people take their place. From this the question arises, what is good documentation for an optimiser? Taking the holistic view of how the technology will deliver value, the documentation needs to support the same two areas that are the focus of the training described above;

Firstly, optimiser use and interpretation. This will normally be the subject of an Optimiser User Guide. However, user guides by default may be strong on usage and weak on interpretation. Hence the focus needs to be on designing the user guide to help the users answer the sort of questions outlined in the proceeding section. This may require updating as experience with optimiser usage develops.

Secondly off-line optimiser model use. The key document here is a detailed technical account of the modelling assumptions and known limitations of the optimiser model.

Business Environment

Asset Leadership

Management support and commitment is a critical element during technology implementation and deployment. At the most basic level, the asset leadership must understand the value that the optimiser brings to the asset. With an understanding of this value, the leadership can ensure that the asset has the correct resources to leverage full value from the technology and actively encourage its use. A key element with the Valhall Field trial was the early engagement of the asset leadership team in the objectives and potential of the technology. This high level support was critical whilst overcoming technical difficulties that arose.

Role of an asset champion

It is clear, for the Valhall Optimiser to be sustainable, it requires an optimiser champion, selected from the operations team, who is in charge of the optimiser and leads user input requirements specification to the optimiser vendor. The optimiser champion needs to have a full understanding of the capabilities and limitations of the optimisation technology and can interact successfully with both the management team and the operations engineers associated with advice implementation.

The champion should understand the optimiser sufficiently to be able to prioritise set point recommendations and present the rationale for the recommendations to the operations team. The champion should also own and maintain optimisation key performance indicators for presentation to the asset management team in order to maintain awareness of performance and value delivery. All value adding insights arising from the use of the technology must be captured and used to re-enforce the technology value to the leadership team.

Multi-Discipline Involvement

An initial problem with the installation of the Valhall optimisation technology was that there was only limited transfer of knowledge of the capability and potential of the technology to the wider cross-disciplinary asset team – technology awareness was essentially limited to the on-shore facilities engineering team. This meant that it was relatively difficult to introduce the optimiser advice into the production optimisation process - the subsurface team had little or no ownership of the optimiser recommendations.

It is also important that the asset is able to bridge a potential credibility gap between the optimisation vendor's deep knowledge of their technology, and the asset team's theoretical and experience based understanding of the plant's behavior. BP's Exploration and Production Technology Group experts have played a key role in this regard. With the technology into an operational phase this expert help is likely to continue but in the form of a remote support capability.

It is clear that an optimisation team is a more sustainable entity than any individual and that the team typically needs to be a cross-disciplinary team involving reservoir, wells operations and commercial. This team will need a management sponsor who will effectively act as the cross-functional steward of the activity and assign resources as required.

Value

The final Valhall learning concerns value, the driver behind a desire for sustainability.

When analysed in detail, the Valhall Optimiser offers two primary sources of value, firstly from improving NGL recovery in the gas and oil processing plant, secondly by adjusting gas plant set points to allow a reduction in HP separator pressure.

The benefit from optimizing the gas plant for NGL recovery obviously varies according to conditions and the commercial environment. At today's throughput and price set the benefit is typically in the region of $10-20k/day. It turns out that all or, at least most, of this benefit is achievable despite the plant instability discussed earlier. With today's throughput, with the gas plant essentially unconstrained, the optimiser recommends a simple operating strategy that can easily be implemented by the operator. It is also true that the strategy could potentially be enforced by a multivariable controller.

The additional benefit predicted by lowering HP separator pressure (typically an additional $30k), is felt to be not achievable on the current plant with current conditions. The reason for this relates directly to the instability issue described earlier. Although the predicted compressor set-point changes are valid on a steady-state model, they cannot be implemented by the operators due to the operating margin that must be maintained to manage process variability.

A key point to re-enforce, in this value discussion, is that the strategies described above are valid for the current plant conditions. At higher throughput or a different gas-lift regime, both strategies are likely to change and, potentially, the second strategy will be able to contribute. The price paid for higher NGL recovery is increased utilisation of compressor power. This is possible when the compressors are under-utilised but, as throughputs increase, the trade off may swing the strategy into reverse to promote throughput over NGL recovery. A higher HP separator pressure may become optimal as gas-lift becomes more significant.

The strength of an optimiser is that it will automatically adjust its strategy in response to the changing conditions. This will always deliver value over other technologies as long as the operators are regularly using the tool and have confidence in its ability to define strategy.

Conclusions

As the length of the learnings section of this paper would suggest, there are many factors that we feel influence the sustainability of optimisation technology. The field trial at Valhall has provided an opportunity for many of these factors to be experienced first-hand and for some solutions to be tested and evaluated. Our understanding has increased significantly and future projects will benefit from this. In overall summary it is useful to pick out what we consider to be some of the key high-level learnings:

- It is a key for an asset considering the application of model-based optimisation technology to understand the full business proposition of the technology. This includes the added value to be expected, the full life-cycle cost of ownership, the technology support model and, most importantly, the asset's organisational and own people requirements.
- Automation of business process is key to sustainability in particular where that process consumes significant resources and is but a step on the way to knowledge and better decisions. There is a lot of low risk opportunity here to enhance sustainability.
- Interpretation of model-based optimisation advice for a production system and process plant is a complex multi-faceted exercise which, with existing technology and our partially developed understanding, is not currently ready for automation within a closed loop system This is not to say closed loop optimisation will not arrive but that BP, the industry and the technology providers have more work to do before it will become a reality. An exception to this is where the optimum strategy is clear and consistent and the process control straight-forward., in which case an advanced control solution is potentially the right on-line optimisation technology.

The challenge for BP is to turn all of the field trial learnings, together with those gathered from other BP businesses and industry, into an effective best practice that can be used by BP's business units and projects to support future optimisation implementations. Because there are many issues still to fully understand and because technology in support of this activity is developing rapidly, such a best practice needs to be a living document subject to regular updates as learnings and technology mature.

Finally, there are some outstanding issues still to be addressed with the Valhall field trial, the most important of which are summarized below:

Rigorous Value Assessment

With the delayed progression of the optimiser into an operate phase, a rigorous assessment of optimiser benefits has yet to be carried out. Current focus is from capturing quick wins from the optimiser and establishing user confidence. However, a rigorous post-implementation assessment will need to be conducted to confirm the benefits being realized by the optimiser and provide specific recommendations on how to extract the maximum business value from the investment.

People to Support the Holistic Model

The Valhall field trial has benefited from a number of key people elements. Two of these have already been mentioned, namely the strong asset leadership support and the openness of the asset operations team. A third factor has been the opportunity to embed, for one year in the operations team at Valhall, a recent graduate engineer with limited operational experience but a very strong background in steady-state and dynamic simulation. It is unusual to have this degree of simulation capability available within a BP asset, and the impact of this on the optimiser sustainability needs to be fully evaluated and the consequence understood for the technology roadmap and the people BP will need to support it.

Acknowledgments

The author would like to acknowledge the following individuals who have contributed significantly to the Valhall field trial and its learnings.

Firstly. the Valhall operations team, in particular Arild Sunde, Patrick Calvert, Tim Griffin, Inger Smedberg Sundfoer, Paal Fister, Paul Hocking and Eldar Larsen.

Secondly, the BP Exploration and Production Technology Group simulation and business transformation teams, in particular Richard Bailey, Dr Stephen Leng, Richard Heddle, Peter Mihalik and David Feineman.

Thirdly, the Emerson Process Management team, in particular Gopal Paul and Glyn Westlake.

Fourthly, the W.S.Atkins team, in particular Prasad Sethuraman.

Finally, the Aspentech Barcelona team, in particular Iban Grau.

References

[1] Newman, M.: Improving Business performance, The Morphix Company, 1996

Figures

Figure 1 - Overview of Valhall process

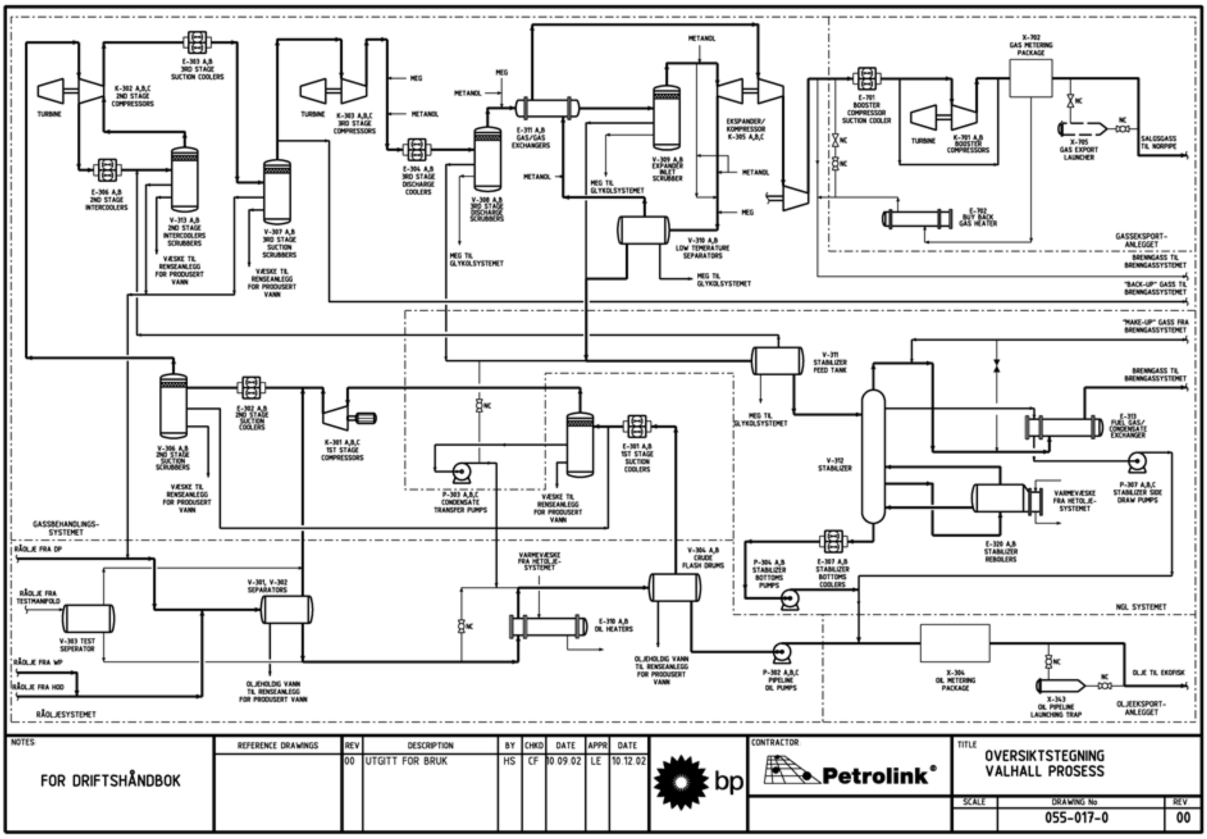
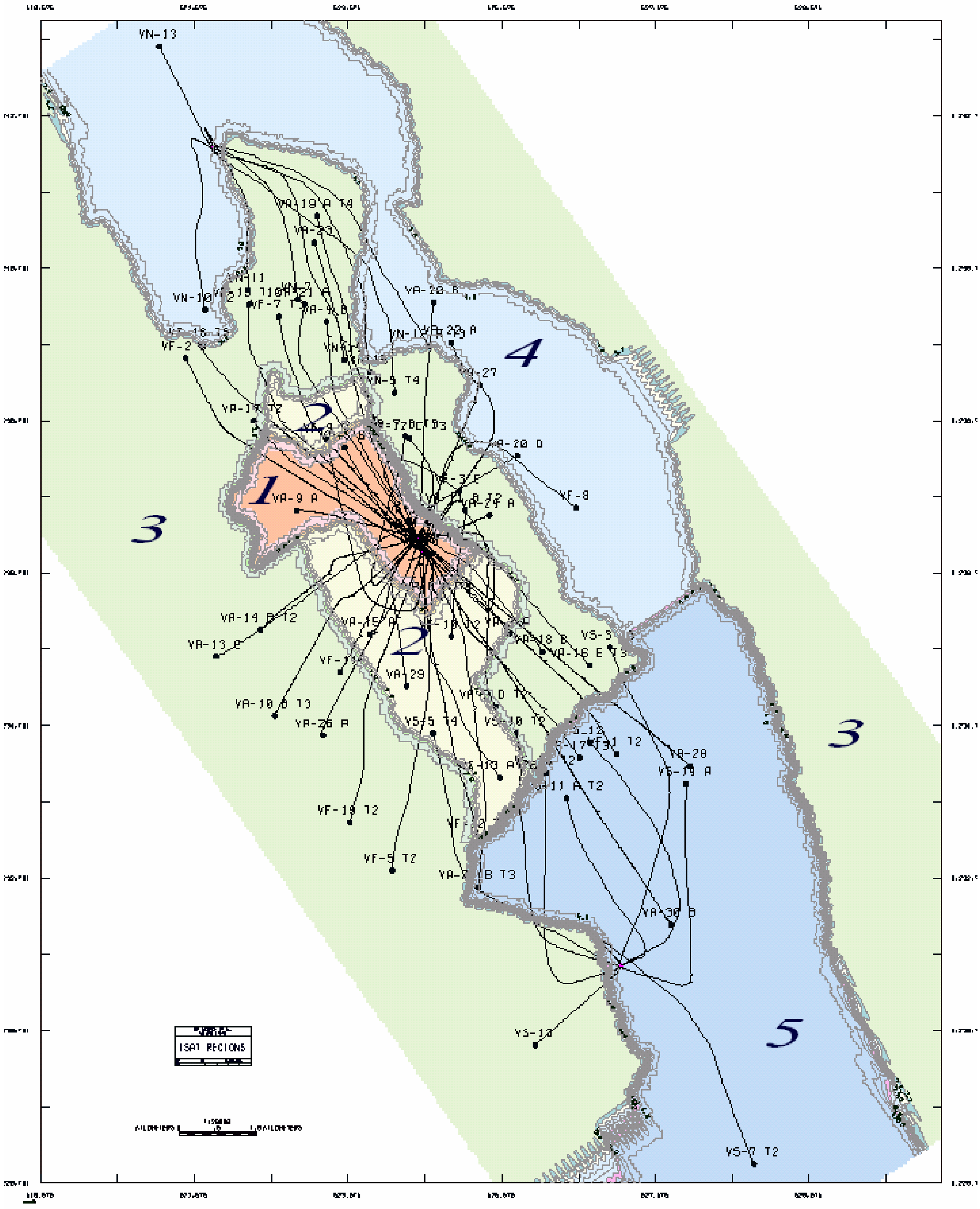


Figure 2 – How the Valhall well models map onto the reservoir compositional regions



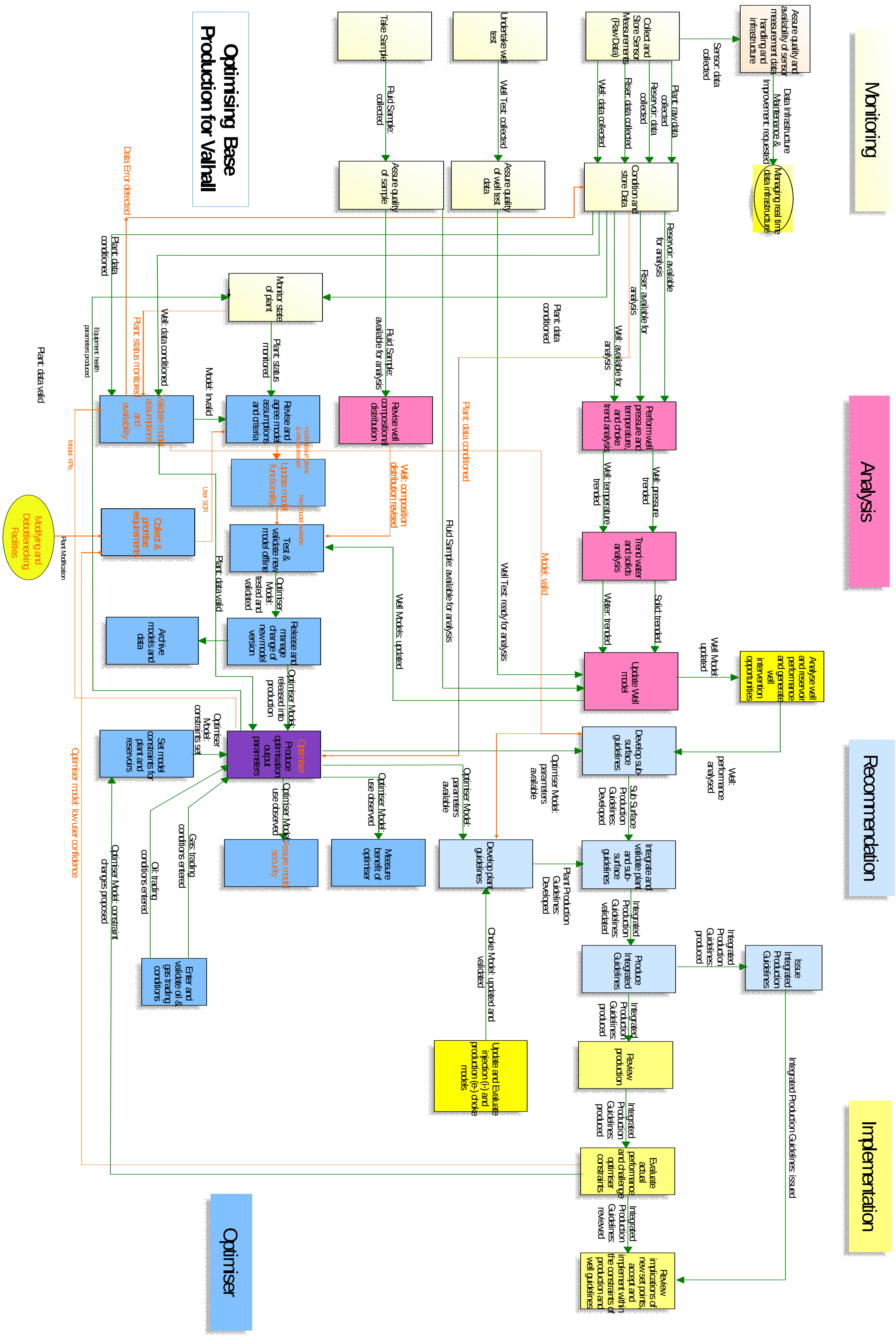


Figure 3 Valhall Optimisation Business Process

Figure 4 – The role of Simulation