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Digitalization of a Giant Field – The Rumaila Story

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Abstract

Objectives/Scope: The Rumaila Operating Organisation (ROO) is a consortium made up of BP, China National Petroleum Corporation (CNPC) and the Basra Oil Company (BOC) formed to manage the rehabilitation and expansion of the Rumaila super giant oil field, considered the third largest in the world. The Digital Oilfield (DOF) plays an important role in the rehabilitation process. This paper describes the major challenges, solutions and benefits over 5 years of implementation.

Methods, Procedures, Process: The development of the DOF solution involved several components: the installation and connection of sensors; a data management platform for both real-time and non-real time data; the development of engineering models and workflows; an Exception-Based Surveillance engine (EBS) and a user interface integrating all this data.

This paper details how an EBS process is handled for a field of this magnitude, the use of state-of-the-art algorithms for identification of well flow conditions, deployment of advanced analytics for surveillance and optimization of natural flow and ESP wells.

This paper also details how usability testing and advanced graphic design practices were used to guarantee maximum adoption of the new toolkit.

Results, Observations, Conclusions: The Rumaila case is ideal for evaluating the added value of digitalization of oilfields since the project developed from a zero base to a fully digital system in a matter of a few years. The main success stories include: the extension of the lifetime of the ESPs; reduction in well downtime; significant time savings for repetitive tasks; improved reservoir management accuracy; the ability to more readily meet production targets; facility management and optimization; and improvement in oil quality.

The data and visualization usage figures which are continuously monitored show a year-on-year growing user base. This demonstrated that maintaining focus on continuous development and evolution, and providing top class support locally and from specialist vendors, increases user adoption.

As a result, the program has gained support at all levels in the organization, making DOF an integral part of the field operation providing high efficiency and standards of excellence.

Novel/Additive Information: Due to the initial lack of any digitalization in the field, this project can be considered a blueprint for modernization of fields in challenging environments, where very little digital

infrastructure is initially available. This project has proven that DOF implementation can be very successful despite many localized challenges, and that a continuous focus on system evolution guarantees a growing user base year after year.

Introduction

The Rumaila Operating Organisation (ROO) is a consortium made up of BP, China National Petroleum Corporation (CNPC) and the Basra Oil Company (BOC) formed to manage the rehabilitation and expansion of the Rumaila super giant oil field, considered to be the third largest in the world.

The definition of a Digital Oilfield (DOF) differs between companies and professionals of different backgrounds. The Digital Oilfield in our opinion is: the gathering real-time and non-real-time data from wells, flowlines, manifolds and production/water injection facilities; the analysis of these data using algorithms, workflows, models, plots, calculations and reports; and user access to this data and analysis on user friendly screens. This allows the engineers to focus on the resulting analysis of the data and the outputs rather than spending a large amount of time searching for, organizing and interpreting the data to come to the same or less precise results or conclusions.

The DOF program has been part of the rehabilitation and expansion plan for the field from the inception of the ROO. The Rumaila oil field presented very specific challenges and opportunities for DOF implementation.

In 2010 when the ROO was formed, no hardware or software DOF solutions were in place. Consequently, full DOF implementation required a unique design solution. This offered interesting opportunities to do things right from the start, however these were accompanied by challenges concerned with practical implementation which will also be discussed in this paper. Today, DOF is an integral and essential part of the day-to-day operations.

This article presents a full roadmap for implementation of the Digital Oilfield program in Rumaila, and details in particular the first steps of the journey: fitting sensors and building production models (the enablers); automating time-consuming repetitive tasks such as reporting (the time-savers); and offering an advanced production surveillance platform (efficiency increase). While these steps may appear basic when compared with state-of-the-art DOF installations, they have brought significant value to ROO, and have required fundamental organization and technology changes to implement.

The way forward is then briefly discussed, where the integrated models are used more intensively.

Finally, the key factors influencing the success or failure of this program are analyzed. Arguably the main driver for success is related more to people than technology. Ensuring the buy-in of the different stakeholders, training and in-house champions as well as access to high quality and reactive support are crucial items.

History and Vision for DOF

When the ROO was formed in 2010, the Rumaila field effectively had no digitalization. The wells and facilities were not equipped with remote sensors, and data was collected manually by teams sent generally daily to the location of the analogue gauges. This data was then faxed or e-mailed back to the central offices. Some of this data was captured in dedicated relational databases, but a lot of the data was stored in a variety of Microsoft Excel files distributed throughout the organization on numerous hard disks and servers. Some of the data was input into integrated asset models (Prosper and GAP from Petroleum Experts) for the purpose of allocation and optimization. The results of such calculations were then communicated through Excel files and PowerPoint presentations.

This situation did not promote optimal decision making. The frequency and accuracy of measurements were unreliable which made understanding the well and reservoir behavior to any degree of accuracy uncertain. Additionally, access to the long-term historical data for the wells was difficult, and the results of the workflows were not exploited uniformly because of the lack of a central repository for such data and results.

To achieve the digitalization of the field and benefits thereof, ROO set the following priorities:

- Define the essential data that was to be collected
- Set up the means of transmitting the data from the field in a reliable and manageable means
- Build a system in the ROO headquarters that would store the data in an organized fashion facilitating easy access to these data by multiple users in various locations
- The use of simple data analytics to quickly provide key interpretive information that would have a positive impact on the field operations and production

The main objectives at the start of the project for digitalization were:

- More frequent and accurate well data for better well work option development
- Reduced losses from ceased wells and SSV closures
- Improved system optimization
- More efficient utilization of the workforce and resources

To achieve these objectives, the digitalization program needed to work on different areas in parallel. A very basic data-gathering and processing system was already in place, shown in Figure 1.

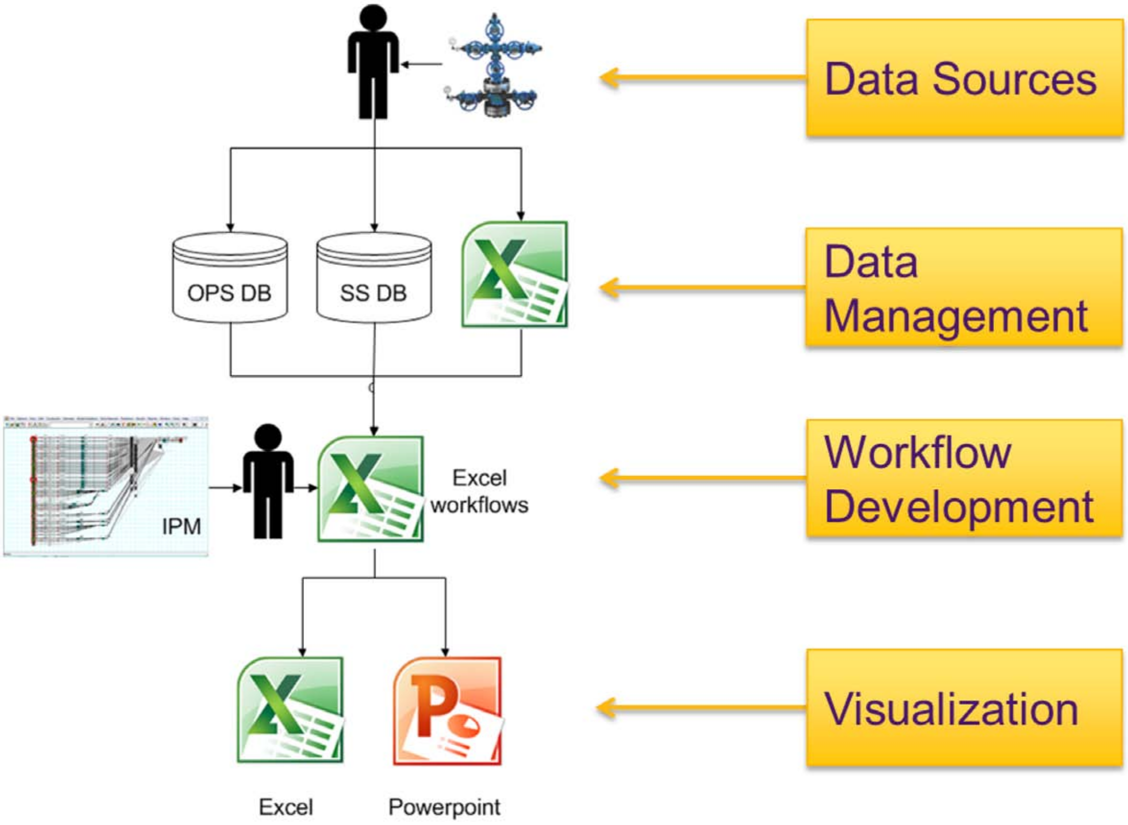


Figure 1—Original Data Capture & Processing

This basic system needed to be significantly enhanced and rebuilt with appropriate data management systems to achieve the DOF objectives:

- Firstly, the source data quality and frequency needed to improve, through the installation of remote sensors and the delivery of robust systems for data capture and transmission.
- Secondly, the data needed to be stored and organized properly, allowing for fast access, extraction and review. Solutions needed to be put in place both for the real-time and non-real-time data.
- Thirdly, the workflows needed to be streamlined, and ported out of Excel. Excel is a powerful solution when used in combination with Open Server, however the long-term maintenance of Excel files is typically difficult and dependent on individual owners, hence the need for a more robust process.
- Finally, a flexible visualization solution needed to be deployed, combining the real-time and non-real-time data, as well as the results of the workflows. Such a solution would not be bounded to only visualization but should also facilitate alarming, exception-based surveillance and automated reporting.

Based on these objectives, a detailed roadmap was built and is presented in Figure 2. The colored boxes represent items that have been completed to date; the white-filled boxes indicate future implementations.

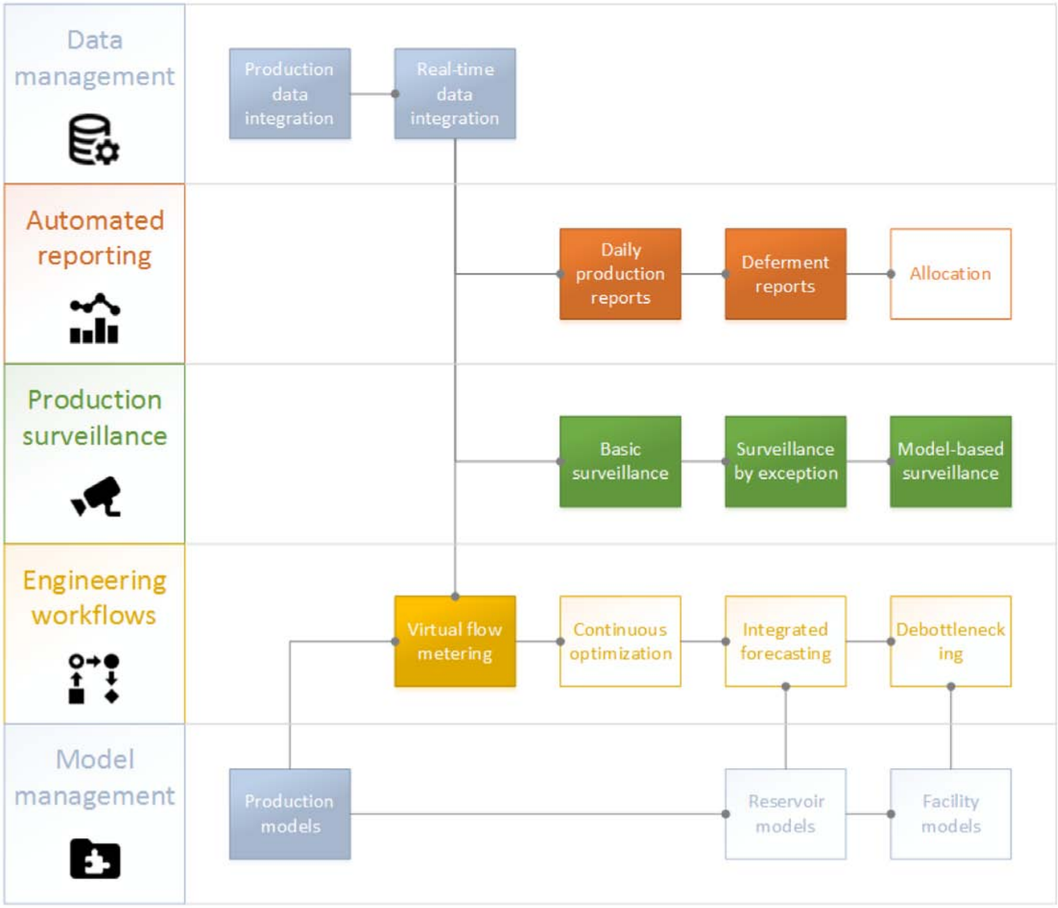


Figure 2—Building blocks to form the DOF solution

The initial focus was on data management, where a robust solution had to be delivered for the management of low frequency production data, and, at the same time, high-frequency sensor data. Due to the co-existence of low and high frequency data (some wells are instrumented, while some others still have local gauges only), especially during the early stage of the project, it was important to find a structure that could seamlessly integrate both data types. FMD (Field Measurement Database) refers to the structure that provides this functionality.

In parallel, the production models (physical models of wells and gathering network) needed to be properly managed, so they could be used by the engineering workflows, in combination with the data.

Once these two steps were achieved, it opened the way for virtual metering. The well models would be triggered on an hourly basis to produce an estimate of the three-phase flow for each well. In parallel, the routine reports were also to be automated.

Figure 3 below shows the project timeline. The installation of the sensors (or RTU's – Remote Telemetry Units) is a long-term activity which started around 2010 and continues today, with the installation now mainly focused on instrumentation of the production (DS – Degassing Stations) and water injection (CPS – Central Pumping Station) process facilities. The data infrastructure has been fully operational since 2014 but has constantly evolved to meet better quality standards. There has been a continuous and heavy focus on the surveillance platform (advanced monitoring system), augmented by the development of workflows. Last, but not least, a systematic maintenance, support and training program has been continuously applied since mid-2014.

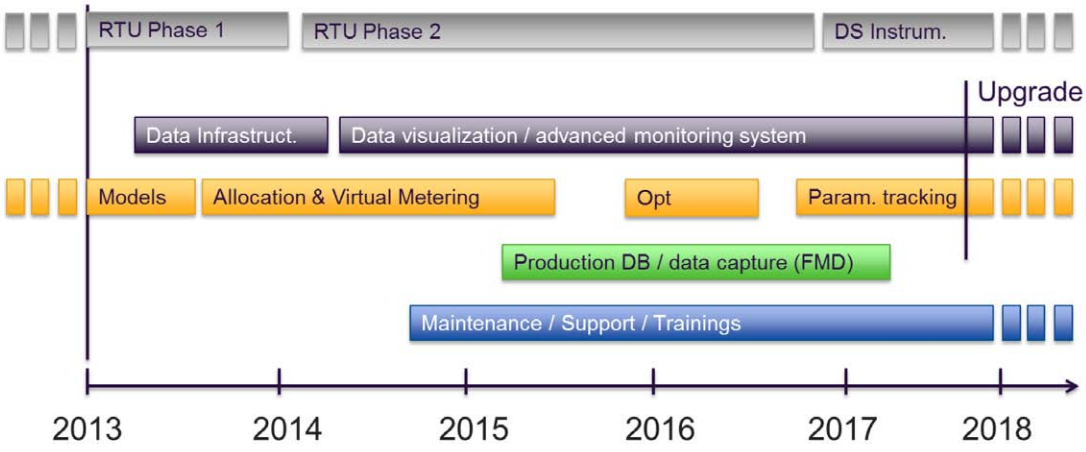


Figure 3—Project timeline

By the end of 2018, a major upgrade to the solution has been undertaken, mostly prompted by new versions of the software used. This upgrade has allowed the opportunity to assess the strong and weak points of the system, to analyze the typical solution usage and to focus on the elements bringing real added value, as well as enhancing the user friendliness and operability of the system.

The Main Achievements

The starting point: installation of sensors and associated hardware

At the start of the project there was no digital or real-time instrumentation installed anywhere in the field. Due to the remote nature of the wells, a priority was the installation of sensors which would allow the determination of well condition. The basic data required as agreed by both Subsurface and Operations engineers comprised: flowline pressure upstream and downstream of the choke; and tubing and annulus temperatures.

Upon deciding the data requirements, the next challenge was to identify the hardware that would be able to provide this data and could cope with the following conditions:

- High temperatures (+50degC) and harsh conditions (sand, dust, wind)
- Remote locations meaning no power supply available

- Also, the remoteness meant that the data needed to be transmitted wirelessly without cables or fiber-optics
- Large number of wells and facilities meaning a robust and repeatable solution for data capture and management

The solution that was reached following several iterations comprised the following hardware:

- Pressure and Temperature wireless transmitters that sent data to a Gateway receiver device. Wireless was important since these transmitters need to be removed and reinstalled regularly during well service and well workover activities.
- Remote Telemetry Unit (RTU) consisting of the Gateway receiver, the internal CPU that included the capability to store data for up to 30 days, and a radio subscriber module that sent the data to the communication towers.
- The power supply which consisted of a heavy-duty battery system and a solar panel. The solar panel charges the batteries during daylight hours and powers up the unit, and the batteries allow for the unit to continue to be powered up during the night, allowing for 24hr coverage.

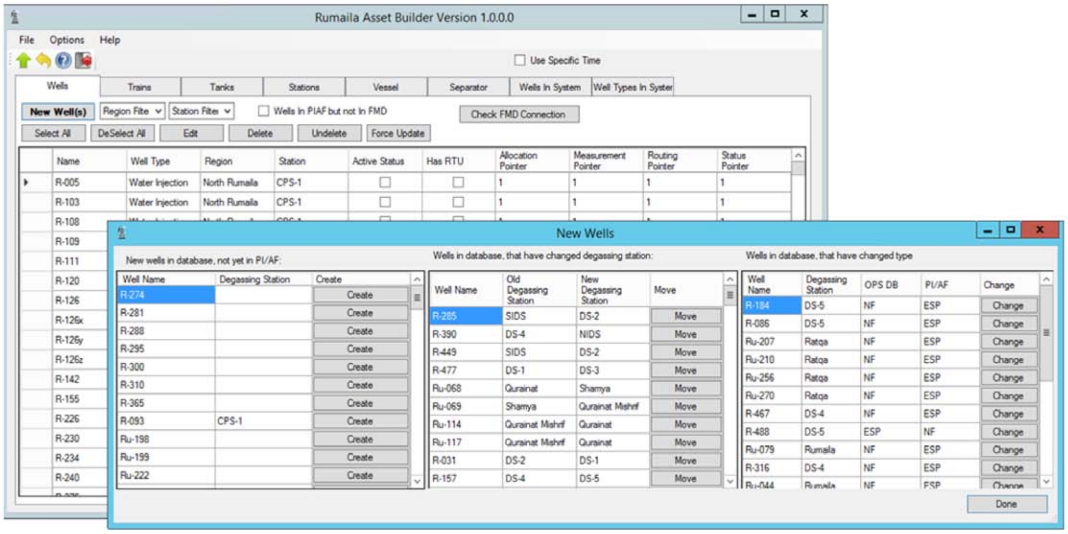
The enablers: data and models

Data storage and integration. The first step was to design a data service layer allowing for the integration of data coming from different sources, namely several relational databases hosting production data, and a PI server for the real-time data. Figure 4 shows the overall architecture of this system. PI/AF (PI Asset Framework) is used as the data integration layer, as well as the data service layer. This architecture allows all DOF components to look in a single place for access to all the data, instead of creating and maintaining links to individual databases. This also means that only this layer needs to be re-configured in case of alteration in the data sources structure. For example, if the structure of a database changes, only PI/AF needs to be re-configured, instead of the different applications using the data (workflow engine, visualization engine and web applications). This also allows to option to add new data sources seamlessly during the project lifecycle.

Figure 4—Data flow

Due to the very large size of the field, and the vast number of wells involved, it was crucial to ease the process of adding (and removing) wells. New wells are routinely drilled, turned into injectors or decommissioned. The data model implemented in PI/AF is significantly complex, and manual interventions were to be avoided as much as possible.

For this purpose, a dedicated tool was built for automating the creation of the underlying complex data model based on a series of simple inputs. The tool interrogates a drilling database to acquire the full list of wells, and the system administrators pick the wells to be included in the system. The tool inserts these wells into the data model, with all the relevant attributes (sensor data, entries in production databases, etc.). Figure 5 shows some of the forms that allow this functionality.



Name	Well Type	Region	Station	Active Status	Has RTU	Allocation Pointer	Measurement Pointer	Routing Pointer	Status Pointer
R-005	Water Injection	North Rumaila	CPS-1	☐	☐	1	1	1	1
R-103	Water Injection	North Rumaila	CPS-1	☐	☐	1	1	1	1
R-108									
R-109									
R-111									
R-120									
R-126									
R-126x									
R-126y									
R-126z									
R-142									
R-155									
R-226									
R-230									
R-234									
R-240									

New wells in database, not yet in PI/AF:

Well Name	Degassing Station	Create
R-274		Create
R-281		Create
R-288		Create
R-295		Create
R-300		Create
R-310		Create
R-365		Create
R-093	CPS-1	Create
Ru-198		Create
Ru-199		Create
Ru-222		Create

Wells in database, that have changed degassing station:

Well Name	Old Degassing Station	New Degassing Station	Move
R-285	SIDS	DS-2	Move
R-390	DS-4	NIDS	Move
R-449	SIDS	DS-2	Move
R-477	DS-1	DS-3	Move
Ru-068	Qurainat	Shamya	Move
Ru-069	Shamya	Qurainat Mishrif	Move
Ru-114	Qurainat Mishrif	Qurainat	Move
Ru-117	Qurainat Mishrif	Qurainat	Move
R-031	DS-2	DS-1	Move
R-157	DS-4	DS-5	Move

Wells in database, that have changed type

Well Name	Degassing Station	OPS DB	PI/AF	Change
R-184	DS-5	NF	ESP	Change
R-086	DS-5	NF	ESP	Change
Ru-207	Ratqa	NF	ESP	Change
Ru-210	Ratqa	NF	ESP	Change
Ru-256	Ratqa	NF	ESP	Change
Ru-270	Ratqa	NF	ESP	Change
R-467	DS-4	NF	ESP	Change
R-488	DS-5	ESP	NF	Change
Ru-079	Rumaila	NF	ESP	Change
R-316	DS-4	NF	ESP	Change

Figure 5—Rumaila Asset Builder software, automating the creation and maintenance of the data model

Integration of DOF systems. In addition to data integration, it was necessary to connect the different systems operating in the DOF space. Figure 6 shows the links between the different systems.

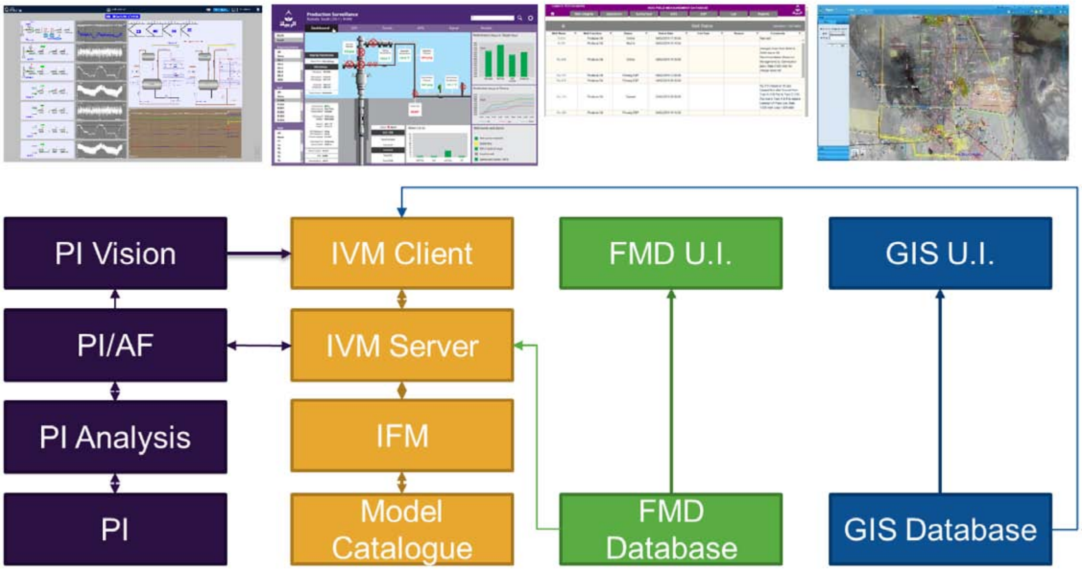


Figure 6—User Interface Platform

The PI suite is used for data modeling, data integration and data visualization for a large audience. It gets input from FMD (the production database) and from the workflow engine.

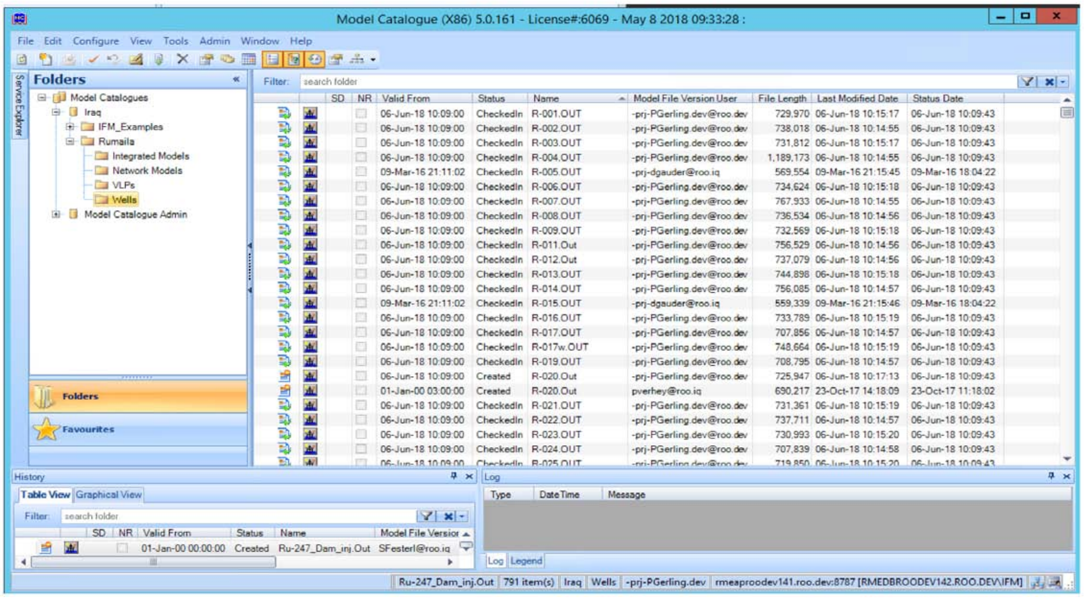
The IVM (Petroleum Experts Integrated Visualisation Management Tool) client is the preferred tool for visualization, and a dedicated set of screens has been developed to utilize this graphical interface.

Management of production models. Once the data was accessible and integrated, and the different systems were able to communicate with one another, the next step was management of the production models.

The maintenance and creation of the production models is handled by several people in ROO. Each individual is given responsibility for a set of wells. These models are subsequently used by automatic workflows for performing virtual metering and production allocation.

The models are managed using a collaborative and centralized environment – the "Model Repository" which all users contribute to. This repository implements sets of permissions, ensuring that only the person responsible for a subset of models can alter them, while all individuals are able to consult them. The system also keeps track of the model updates, allowing trending of the model parameters over time, and the option to revert to a previous version in the case of a mistake being made.

Such a central repository is also essential for the automatic workflows, since they need to be able to get the latest and most up to date model at any time. Figure 7 shows the screen used to access the models.



SD	NR	Valid From	Status	Name	Model File Version User	File Length	Last Modified Date	Status Date
	☐	06-Jun-18 10:09:00	CheckedIn	R-001.OUT	-prj-PGerling.dev@roo.dev	729,970	06-Jun-18 10:15:17	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-002.OUT	-prj-PGerling.dev@roo.dev	738,018	06-Jun-18 10:14:55	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-003.OUT	-prj-PGerling.dev@roo.dev	731,812	06-Jun-18 10:15:17	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-004.OUT	-prj-PGerling.dev@roo.dev	1,189,173	06-Jun-18 10:14:55	06-Jun-18 10:09:43
	☐	09-Mar-16 21:11:02	CheckedIn	R-005.OUT	-prj-dgauder@roo.iq	569,554	09-Mar-16 21:15:45	09-Mar-16 18:04:22
	☐	06-Jun-18 10:09:00	CheckedIn	R-006.OUT	-prj-PGerling.dev@roo.dev	734,624	06-Jun-18 10:15:18	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-007.OUT	-prj-PGerling.dev@roo.dev	767,933	06-Jun-18 10:14:55	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-008.OUT	-prj-PGerling.dev@roo.dev	736,534	06-Jun-18 10:14:56	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-009.OUT	-prj-PGerling.dev@roo.dev	732,569	06-Jun-18 10:15:18	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-011.Out	-prj-PGerling.dev@roo.dev	756,529	06-Jun-18 10:14:56	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-012.Out	-prj-PGerling.dev@roo.dev	737,079	06-Jun-18 10:14:56	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-013.OUT	-prj-PGerling.dev@roo.dev	744,898	06-Jun-18 10:15:18	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-014.OUT	-prj-PGerling.dev@roo.dev	756,085	06-Jun-18 10:14:57	06-Jun-18 10:09:43
	☐	09-Mar-16 21:11:02	CheckedIn	R-015.OUT	-prj-dgauder@roo.iq	559,339	09-Mar-16 21:15:46	09-Mar-16 18:04:22
	☐	06-Jun-18 10:09:00	CheckedIn	R-016.OUT	-prj-PGerling.dev@roo.dev	733,789	06-Jun-18 10:15:19	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-017.OUT	-prj-PGerling.dev@roo.dev	707,856	06-Jun-18 10:14:57	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-017w.OUT	-prj-PGerling.dev@roo.dev	748,664	06-Jun-18 10:15:19	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-019.OUT	-prj-PGerling.dev@roo.dev	708,795	06-Jun-18 10:14:57	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	Created	R-020.Out	-prj-PGerling.dev@roo.dev	725,947	06-Jun-18 10:17:13	06-Jun-18 10:09:43
	☐	01-Jan-00 03:00:00	Created	R-020.Out	pverhey@roo.iq	690,217	23-Oct-17 14:18:09	23-Oct-17 11:18:02
	☐	06-Jun-18 10:09:00	CheckedIn	R-021.OUT	-prj-PGerling.dev@roo.dev	731,361	06-Jun-18 10:15:19	06-Jun-18 10:09:43
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	☐	06-Jun-18 10:09:00	CheckedIn	R-023.OUT	-prj-PGerling.dev@roo.dev	730,993	06-Jun-18 10:15:20	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-024.OUT	-prj-PGerling.dev@roo.dev	707,839	06-Jun-18 10:14:58	06-Jun-18 10:09:43
	☐	06-Jun-18 10:09:00	CheckedIn	R-025.OUT	-prj-PGerling.dev@roo.dev	719,850	06-Jun-18 10:15:20	06-Jun-18 10:09:43

SD	NR	Valid From	Status	Name	Model File Versior
	☐	01-Jan-00 00:00:00	Created	Ru-247_Dam_inj.Out	SFesterl@roo.iq

Figure 7—Screenshot of the Model Cataloging software used to manage the physical models

The time-savers: Automated production reporting, data capture and QC

There are many elements of the DOF system which contribute to the transformation of low-value-added time into high-value-added time for the engineers.

The manual data capture process has been eliminated; the data quality check is largely automated; automatic workflows replace manual calculations; and many routine reports are automated. For example, reports about ESP performance, well uptime and data quality are generated daily and automatically.

It has been estimated that the manual labor required to do data collection has been reduced by a factor 10 compared to that expended in 2011. This has allowed the ROO to reassign personnel to higher value-added tasks and has contributed to overall field performance improvements.

This time saving has been accompanied by a reduction in exposure to HSSE risks because of the reduction of the number of trips to the wells or facility by the field crews.

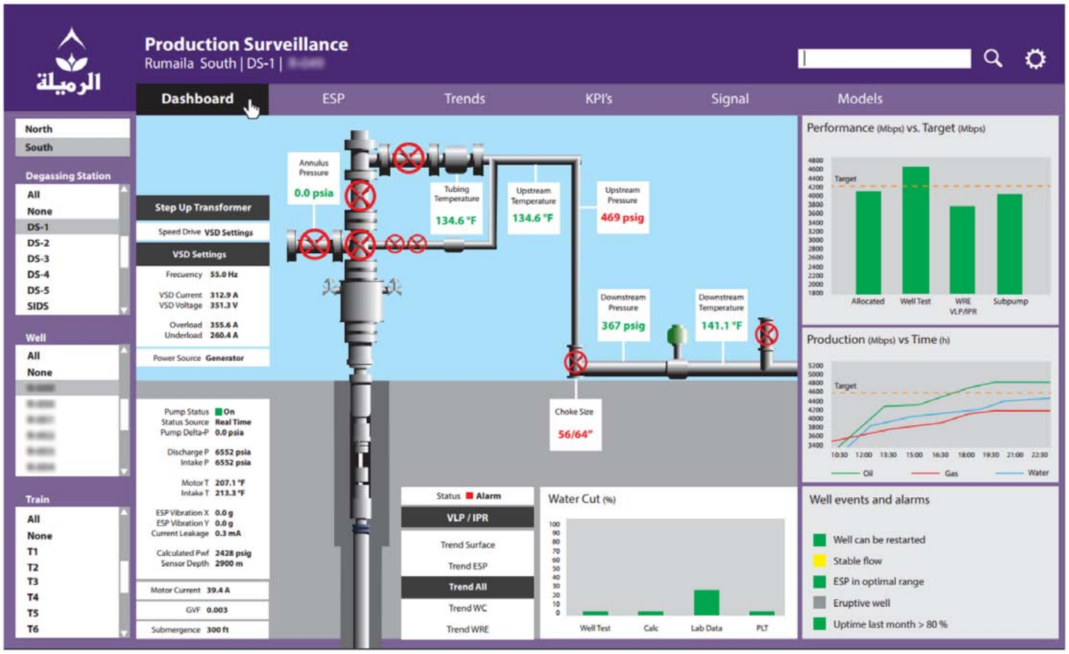
Efficiency increase: Advanced surveillance platform

Step 1: Access to real-time and non-real-time data within a single system. The main objective was to gather all the critical data for continuous surveillance into a single, user friendly system. Completion of this objective was relatively challenging due to the nature of the existing data systems and the variety of different products that were available to deliver the solution.

This data is exposed to IVM (the visualization platform) from Petroleum Experts. PI/AF configures all the outputs from the IVM software in a straightforward manner. A significant proportion of the effort went into the design of the surveillance screens, which provide information about:

- The physical setup of the well (gauges, etc.)
- The real-time data
- The non-real-time data captured manually
- The flow status and flow path of the wells
- The processing facility the well is connected to (dynamic)
- The results from model-based calculations
- The difference between the actual well production and its production target
- Data quality and measurement alarms
- Well configuration information (such as ESP type, etc.)

An example is shown in Figure 8.



Annulus Pressure 0.0 psia
Tubing Temperature 134.6 °F
Upstream Temperature 134.6 °F
Upstream Pressure 469 psig
Downstream Pressure 367 psig
Downstream Temperature 141.1 °F
Choke Size 56/64"

Speed Drive VSD Settings
Frecuency 55.0 Hz
VSD Current 312.9 A
VSD Voltage 351.3 V
Overload 355.6 A
Underload 260.4 A
Power Source Generator

Pump Status 🟩 On
Status Source Real Time
Pump Delta-P 0.0 psia
Discharge P 6552 psia
Intake P 6552 psia
Motor T 207.1 °F
Intake T 213.3 °F
ESP Vibration X 0.0 g
ESP Vibration Y 0.0 g
Current Leakage 0.3 mA
Calculated Pwf 2428 psig
Sensor Depth 2900 m
Motor Current 39.4 A
GVF 0.003
Submergence 300 ft

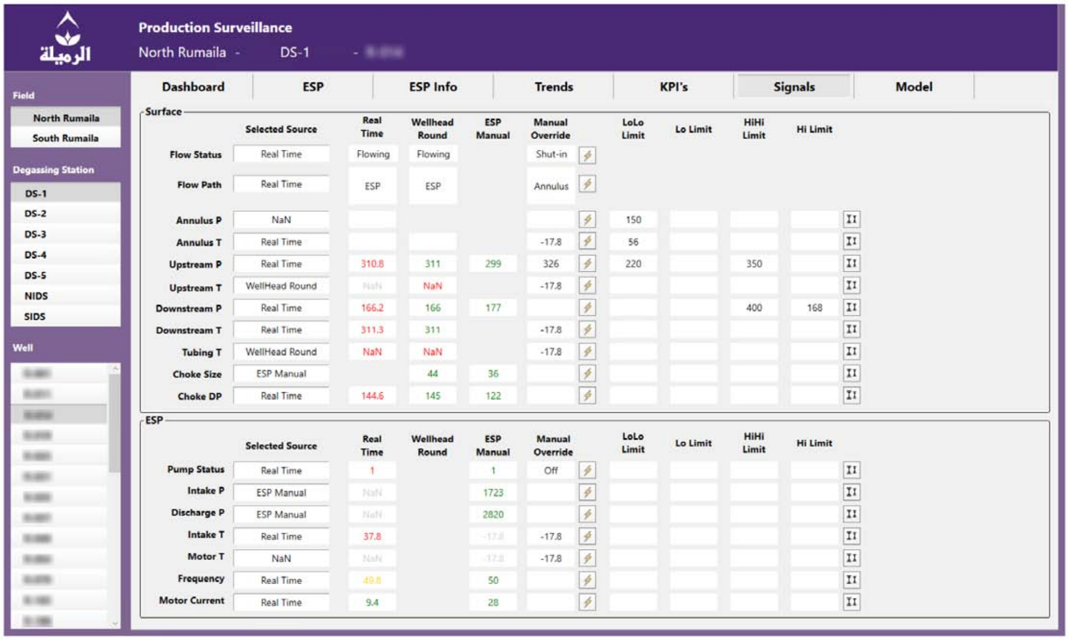
Status 🟥 Alarm

🟩 Well can be restarted
🟨 Stable flow
🟩 ESP in optimal range
⬜ Eruptive well
🟩 Uptime last month > 80 %

Figure 8—Well main screen Dashboard

An automatic protocol was put in place for determining the most accurate source of information in case of redundant data. The user can review the data that has been selected and overrides the automatic selection if required. Figure 9 is an example of the screen that allows the user to select the appropriate source of data.

To conclude, this visualization system has provided a single set of views for the data which has led to accurate and consistent information being available to all the users.



Surface

	Selected Source	Real Time	Wellhead Round	ESP Manual	Manual Override	LoLo Limit	Lo Limit	HiHi Limit	Hi Limit
Flow Status	Real Time	Flowing	Flowing		Shut-in				
Flow Path	Real Time	ESP	ESP		Annulus				
Annulus P	NaN					150			
Annulus T	Real Time				-17.8	56			
Upstream P	Real Time	310.8	311	299	326	220		350	
Upstream T	WellHead Round	NaN	NaN		-17.8				
Downstream P	Real Time	166.2	166	177				400	168
Downstream T	Real Time	311.3	311		-17.8				
Tubing T	WellHead Round	NaN	NaN		-17.8				
Choke Size	ESP Manual		44	36					
Choke DP	Real Time	144.6	145	122					

ESP

	Selected Source	Real Time	Wellhead Round	ESP Manual	Manual Override	LoLo Limit	Lo Limit	HiHi Limit	Hi Limit
Pump Status	Real Time	1		1	Off				
Intake P	ESP Manual	NaN		1723					
Discharge P	ESP Manual	NaN		2820					
Intake T	Real Time	37.8		-17.8	-17.8				
Motor T	NaN	NaN		-17.8	-17.8				
Frequency	Real Time	49.8		50					
Motor Current	Real Time	9.4		28					

Figure 9—Well main screen Signals

Step 2: Surveillance by Exception. The principal behind Surveillance by Exception is that important information is brought to the users' attention ahead of less important data. Due to the large size and number of wells in the Rumaila field, implementing surveillance by exception is a key feature. Indeed, with many hundreds of wells producing and injecting continuously, it would be prohibitively time consuming to cycle through each well in turn carrying out condition or alarm monitoring.

To achieve this, algorithms were developed which prioritized and ranked the wells status according to criteria such as: flowing/not-flowing; wells changing status in the last 24 hours; deviation of measured parameters from target, etc. Figure 10 is an example of the screen that highlights certain wells for specific attention.

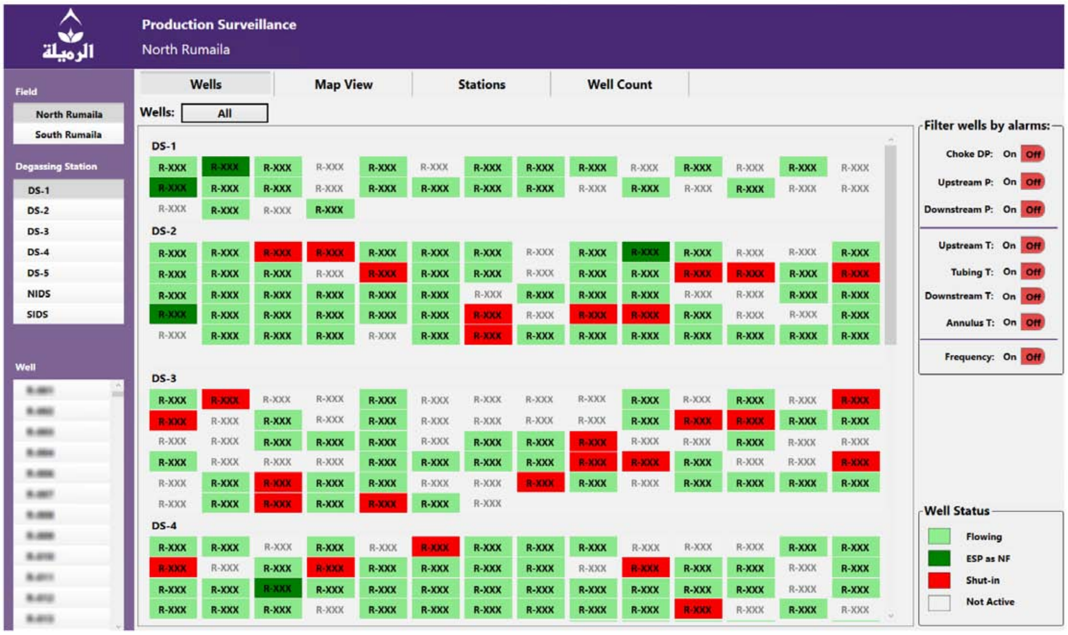


Figure 10—North Rumaila Dashboard screen

An alarm system was then configured. The visualization platform, IVM, embeds this functionality. Rules have been configured which define the acceptable operating ranges for critical parameters. E-mail alerts are sent automatically to the designated responsible persons in case of violation of these bounds.

This real time condition monitoring and alarm system has delivered significant efficiency improvements. Figure 11 shows an example of a major well that was shut-in unintentionally because of a problem with the SSV. This issue was detected by the DOF system, and action was taken, and the well was restarted in less than 2 hours. Such a problem could have gone undetected for days or weeks prior to the implementation of the DOF system.

From: [redacted] Sent: [redacted]
To: [redacted]
Cc: [redacted]
Subject: [redacted]

Gents,

Looking at IVM alarms this evening, we have had an SSV closure on [redacted] this afternoon at 17:40 – **the last allocated production for this well was 6.2 mbd** – **BIG WELL.**

Can you please send team to check the status and re-open if confirmed?

Thanks
[redacted]

From: [redacted]
To: [redacted]
Cc: [redacted]
Subject: [redacted]

[redacted]

Re-opened very promptly at 19:30!! Good job all round!!

[redacted]

Figure 11—Real example of restoring production in less than 2hrs.

Moving to exception-based surveillance has freed up significant time for the engineers. Now, only 3 monitoring engineer positions are dedicated to operating the exception-based surveillance platform which monitors the entire field. These positions are manned 24/7.

Step 3: Model-based surveillance. With the basic surveillance system in place, the production hydraulic models were then incorporated to provide enhanced information and surveillance for the DOF solution.

Smart flow status

A priority for ROO for efficient field monitoring was to determine unambiguously whether a well was flowing or not. This may sound trivial but prior to implementation of DOF this was a hugely labor intensive and time-consuming activity.

Several iterations were required before a reliable system of logic could be developed to determine the flow status of a well. The approach taken used all available measurements as input and applied a weighting to each to allow computation of the flowing status along with a confidence parameter. Initial results showed that surface flowing temperatures were the most reliable for this calculation. A complication that had to be dealt with during subsequent iterations in the logic was the significant temperature variation between day and night in Rumaila. To account for this, a specific ambient temperature probe was installed, and this parameter was included in the final logic.

Virtual metering

ROO is currently using the Petroleum Experts IPM suite for the physical modeling of its fields. A purpose-built workflow has been designed to perform continuous virtual metering on all wells. This workflow was complicated by the design of most of the Rumaila production wells which allow flow through the tubing, or the annulus, or both, as can be seen in Figure 12. Consequently, detection of the flow path is required before triggering the calculations from the hydraulic model. Accurate implementation of this calculation is dependent on whether there is flow through the tubing or annulus or not, as previously described.

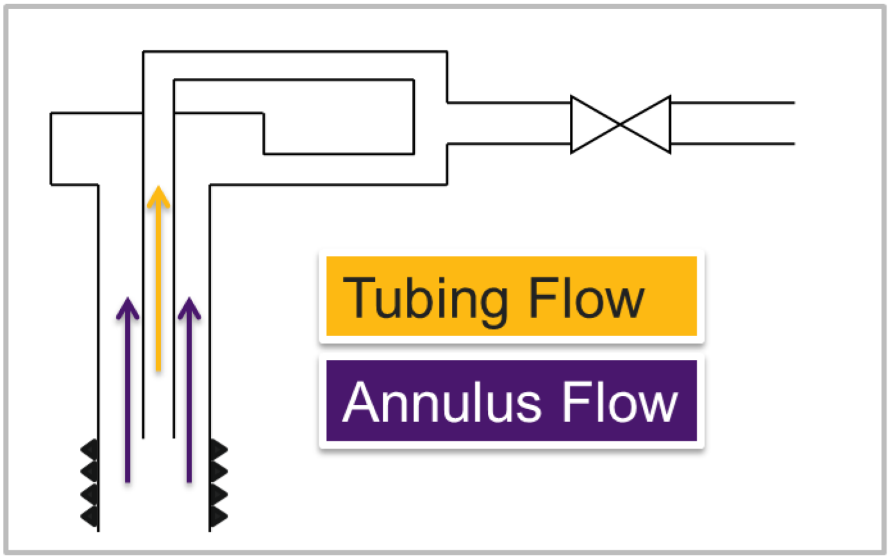


Figure 12—Flow path of natural flow wells

This workflow allows quantification of the production of every well in real time, in the absence of flow meters. For wells equipped with a downhole gauge, it also allows the calculation of the watercut on a real-time basis. The well rates determined from this workflow are available for comparison with the latest production well tests and have proven useful for early problem and opportunity optimization identification.

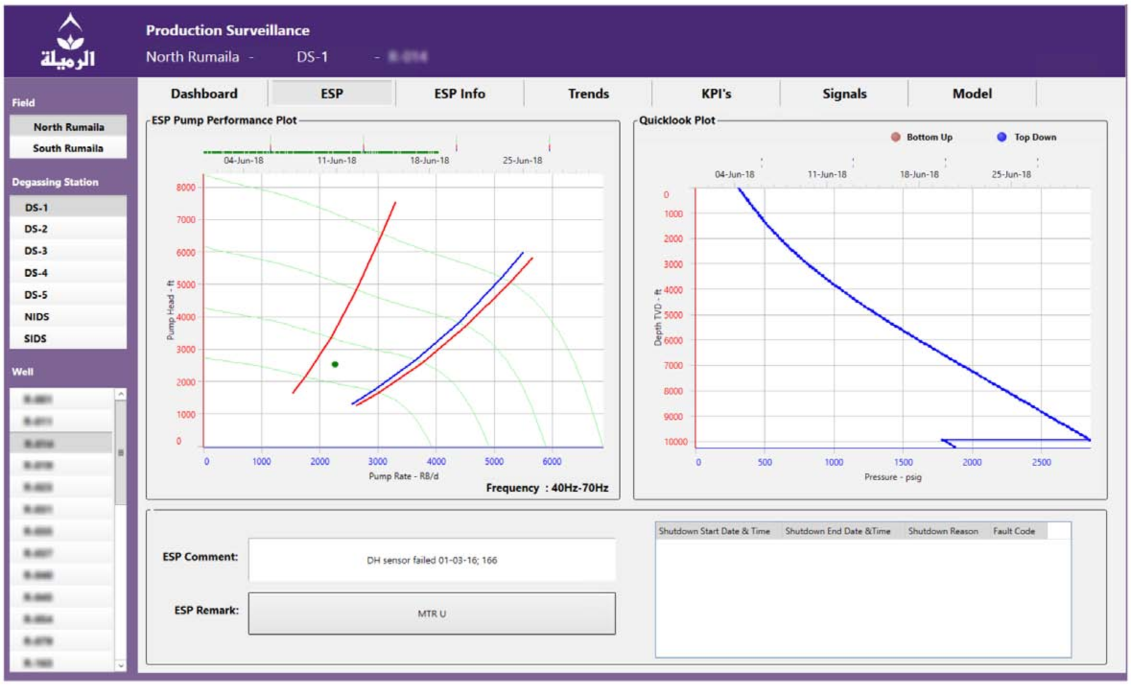
ESP advanced diagnosis

A significant proportion of Rumaila wells are artificially lifted with electrical submersible pumps. To maximize ESP run-life and avoid unexpected shutdowns, it is essential to monitor the operating conditions and to keep the system working within the prescribed operating envelope.

The DOF solution supports advanced monitoring of these ESP's by leveraging real-time data and bespoke alarms, in conjunction with the integrated models. The ESP wells are modelled in real time using Petroleum Experts' Prosper software which allows IVM to display the performance curve and to locate the position of the pump's running condition within the operating envelope. Figure 13 is an example of the display for this advanced surveillance solution.

In addition to exposing all the data related to the pump and associated motor, the system presents the pump performance curves along with the actual operating points, a visualization of the real-time pressure gradient in the well, a benchmark of the pump uptime against the whole field, a log of the latest shut-down events from the real-time data acquisition system. The system also allows the ESP engineers to log comments manually.

This detailed well-by-well approach is complemented by an overall view of the ESP performance at the full field level by aggregating all ESP data across the field.



Frequency : 40Hz-70Hz

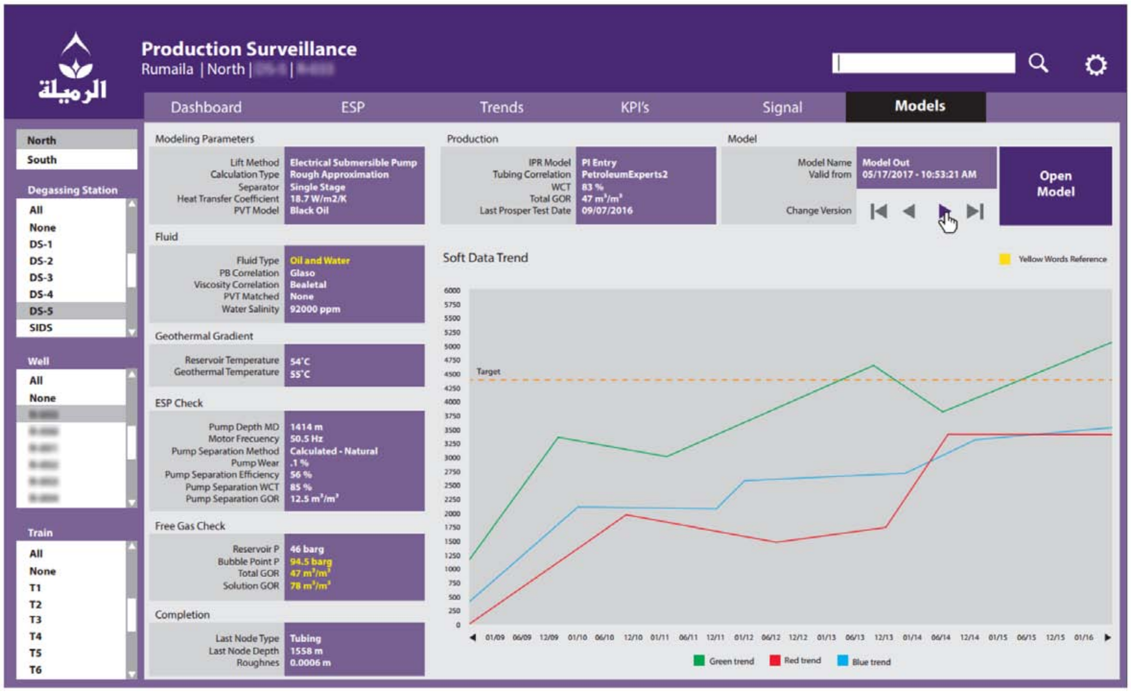
ESP Comment: DH sensor failed 01-03-16; 166

ESP Remark: MTR U

Figure 13—ESP Pump Performance screen within IVM

Model quality monitoring

Since the advanced monitoring solutions were so reliant on the use of well models, the ability to quickly assess the status of the models was provided through dedicated summary screens – an example of which is shown in Figure 14.



Modeling Parameters

Lift Method: Electrical Submersible Pump
Calculation Type: Rough Approximation
Separator: Single Stage
Heat Transfer Coefficient: 18.7 W/m2/K
PVT Model: Black Oil

Fluid

Fluid Type: Oil and Water
PB Correlation: Glaso
Viscosity Correlation: Bealetal
PVT Matched: None
Water Salinity: 92000 ppm

Geothermal Gradient

Reservoir Temperature: 54°C
Geothermal Temperature: 55°C

ESP Check

Pump Depth MD: 1414 m
Motor Frecuency: 50.5 Hz
Pump Separation Method: Calculated - Natural
Pump Wear: .1 %
Pump Separation Efficiency: 56 %
Pump Separation WCT: 85 %
Pump Separation GOR: 12.5 m³/m³

Free Gas Check

Reservoir P: 46 barg
Bubble Point P: 94.5 barg
Total GOR: 47 m³/m³
Solution GOR: 78 m³/m³

Completion

Last Node Type: Tubing
Last Node Depth: 1558 m
Roughnes: 0.0006 m

Production

IPR Model: PI Entry
Tubing Correlation: PetroleumExperts2
WCT: 83 %
Total GOR: 47 m³/m³
Last Prosper Test Date: 09/07/2016

Model

Model Name: Model Out
Valid from: 05/17/2017 - 10:53:21 AM

Figure 14—Well model input summary screen

Step 4: Increase the coverage of DOF to the degassing stations and water injection facilities. The initial phase of the project focused primarily on the wells. Subsequently a program was initiated to install instrumentation in the degassing stations (DGS) which process the oil, and the pumping stations (CPS) which inject water for the waterfloods. Surveillance screens for the facilities had been developed previously using PI Vision. These existing screens were directly embedded as web pages into the DOF screens rather than rebuilding them in the IVM visualizations. Now the single asset hierarchy contains facility data in addition to well data.

A similar approach was taken for viewing geographical information. Access to the GIS information is accessible using a web service and the DOF visualization receives the graphical data and overlays information such as production rates on top of it, an example of which is shown in Figure 15.

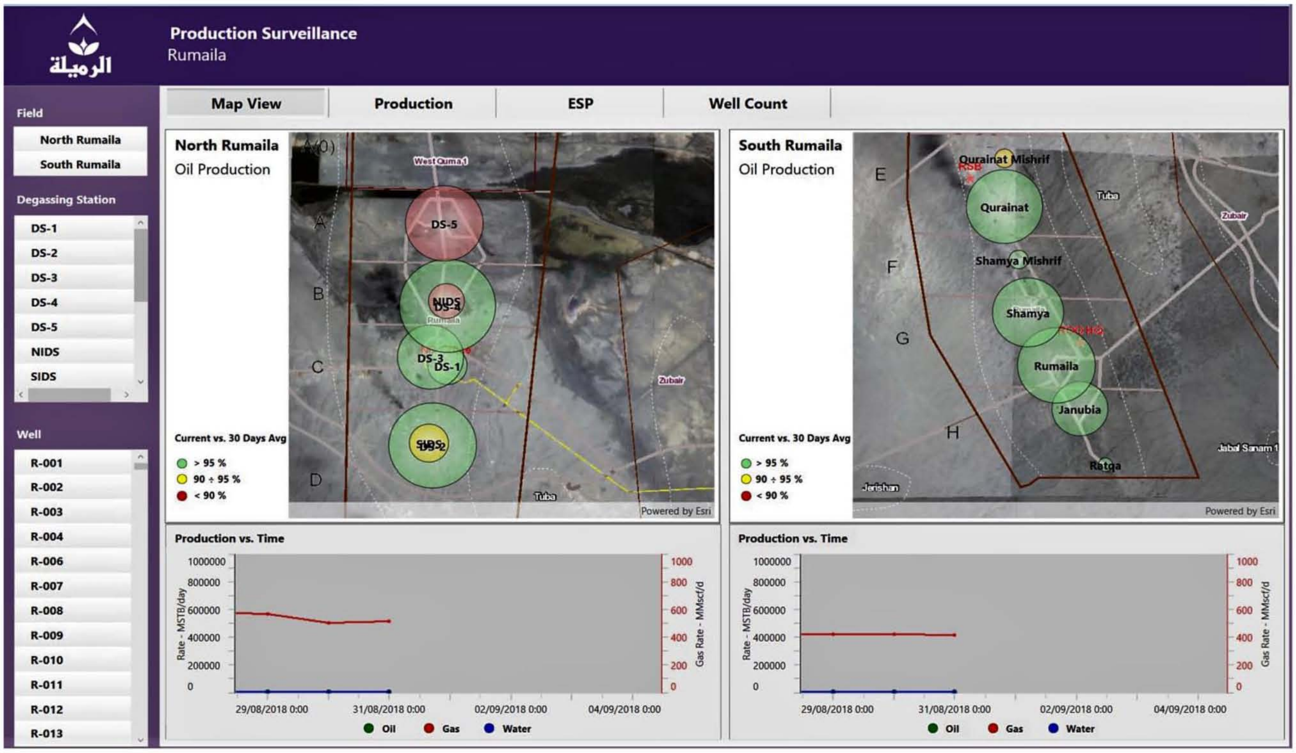


Figure 15—Integration with GIS

The Way Forward

Today the essential building blocks of the digital oilfield are in place. Nearly all wells are instrumented; the data transmission, storage and organization are in place; and the production models are built and maintained. Automatic reports are progressively replacing manual ones, and the surveillance platform is used routinely by many users.

This optimization and automation of the tasks and routines that Petroleum Engineers normally execute is now being done through engineering workflows. These workflows are executed at specified time intervals. This increases the accuracy and reliability of the routines as real-time data is used to feed the calculations. For example, for an ESP well the routine takes all the real-time parameters including the wellhead and downhole pressures, temperatures and VSD frequency and runs the Prosper model to calculate the rate. More workflows and routines are presently being implemented which will further enhance the DOF solution.

All elements are now in place for using the production models more intensively and continuously. The virtual metering workflow has provided the necessary data for automating the back-allocation procedure and has enabled continuous reporting. Not only will this workflow increase the accuracy of the back-allocation, it will also free up engineering time to review the results of the back-allocation, and troubleshoot production issues, rather than spending time gathering and formatting data.

A continuous production optimization workflow is becoming more and more feasible, relying on calibrated well models and trustworthy real-time data. A first approach will consist of optimizing the wells on an individual basis, before going into network and routing optimization, which will require additional modeling of the surface facilities.

Key Factors Influencing Success

Human factors

The adoption and ownership of the DOF system by the key users (petroleum engineers, production technologists, reservoir engineers, etc.) is probably the most crucial factor in every DOF deployment. Figure 16 below lists the key factors contributing to this projects success.

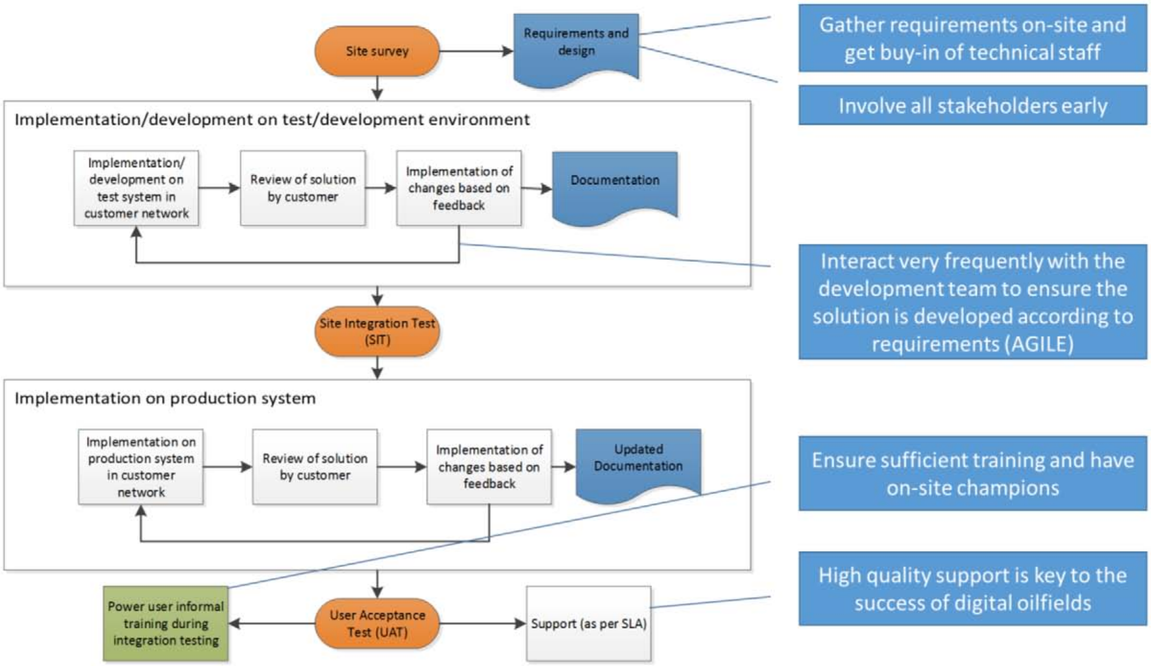


Figure 16—Key factors to success during project execution

Start from the user requirements to design the platform, and not the other way around. A "one size fits all" DOF solution which delivers standard workflows and dashboards may be a cheaper option, but this approach is unlikely to achieve a critical level of user acceptance. This is especially true in operations with a given set of specific operating conditions, such as those found in the ROO. A system designed without early collaboration with the technical users is likely to face uptake and acceptance issues.

A much more successful approach is to engage with the technical personnel directly at the design stage. In this way the solution can address the specific needs of their function and can be designed to simplify and improve their day-to-day activities.

Involve all stakeholders from the start. Identification of all the stakeholders at the start of the project will allow their inclusion at the earliest possible and most appropriate time. The typical stakeholders of a DOF project are the petroleum engineers, the reservoir engineers, the operations team, and the IT department.

Develop in-house DOF champions. It is very advantageous if DOF systems are steadily promoted internally during the implementation stage. A method that worked well for the ROO was the nomination of dedicated DOF Champions. These champions were given extra coaching and training and were first point contacts for the users; and they were able to address feature requests and technical questions. They were also involved in the discussions regarding further development and were vital in obtaining feedback from the users.

Plan for appropriate training. Despite efforts to ensure a user-friendly design, it was recognized that not all capabilities were self-explanatory, and appropriate training was planned and scheduled. For the ROO, a "train the trainer" approach was used. The DOF champions received continuous training on the DOF solution through their intimacy with the project execution and were used subsequently to train the different users in-country and on the job. This has proven to be cost-effective and allowed the training to focus on the actual challenges of the operations. It also reduced the logistics normally associated with training.

Invest in sustainability. ROO placed a high value on system reliability, availability, accuracy and its ability to meet the needs of the users. It was recognized that failure in any of these areas would result in loss of confidence and enthusiasm in the users. Primary IT support was critical in maintaining reliability and availability (for troubleshooting of network issues, maintenance of the servers, etc.). This was so critical that secondary and, in some cases, tertiary support was also planned for and made available. This additional support included the vendors of the hardware and software.

Keep DOF evolving. An evolving system is one that allows for and encourages changes for the better. To keep the DOF system live and to keep the users invested in its success, the facility to record user suggestions for improvements or changes needs to be available. Failure in this respect will lead to lack of engagement, or in the worst cases reversion to old solutions such as unmanageable, unmaintainable and unauditable Excel spreadsheets. It is recommended that, as in ROO, there be a budget provision for continuous evolution of the system.

Conclusion

The Digital Oilfield has truly transformed the way Rumaila is operated. Operations have become safer, efficiency has improved, and engineers are working smarter. ESP run-life has been extended, well downtime reduced, and repetitive tasks eliminated. Reservoir management has been tuned and facilities are better managed and optimized.

To realize the Digital Oilfield from scratch has been a major undertaking which has spanned more than 5 years. It has involved installing sensors, an infrastructure for data transmission, data management solutions, workflow engines, visualizations and technical dashboards. Coordinating these implementations in parallel resulted in rapid and early returns on investment

ROO places high value on the ability of their DOF system to evolve, and significant investment has been made in ensuring that an infrastructure exists which can support this. Success of the system can be judged by the usage figures which continue to steadily increase across the organization. Rumaila's implementation of DOF demonstrates the significant success that can be achieved with huge brown field installations.