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The Results of Deming Cycle Concept Implementation into Oil Production Processes

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Abstract

The work analyzes the results of the implementation of the Production Management System (hereinafter System), based on the concept of the Deming Cycle. The system allows automatic selection of Well Interventions, integrated planning of production activities, as well as calculate the production forecast using an integrated field model.

The system uses Big Data technologies, optimization algorithms for various target functions, machine learning methods. The system implements automation of typical tasks, solved by such specialists as geologist, production technologist, reservoir engineers, economist, risk manager. This allows to issue effective recommendations for various production activities on the asset. These recommendations pass the stage of approval by real experts of the Company, after which, based on optimization algorithms, an integrated plan of operational activities is formed. Based on the received integrated plan, the production profile is calculated taking into account interference effects from each of the activities. Then the fact of the planned activities is monitored, on the basis of which the expert system is self-learning in order to improve the accuracy of planning in future.

A significant number and not always satisfactory quality of the data required for the operation of the System, available at the Company, led to the need to develop additional algorithms that are able to work in the case of a limited amount of data. The results of the work in this case require a deeper analysis by field specialists before making a decision. To understand the reliability of the results obtained, the Risk parameter was introduced into the System, which clearly demonstrates which of the recommendations are based on less reliable data and use less accurate methods for evaluating the effects from the activity.

Thanks to the implementation of the Production Management System, significant results have been achieved in terms of reducing bottlenecks and optimizing operating costs. In particular, due to better integrated planning with regard to the selection of measures, taking into account their compatibility, the shortfalls were reduced by more than 10%. By improving the quality of monitoring the effectiveness of planned activities and the corresponding automatic System self-learning, it was possible to achieve a reduction in operating costs by more than 2%.

Introduction

Most of the world's oil companies are currently implementing or planning the implementation of similar Production Management Systems. However, at the moment the most of these systems exist only in the form of concepts. To date, System is the first implemented self-learning system with elements of artificial intelligence that successfully implements the concept of the Deming Cycle in the territory of the Russian Federation.

Despite the state's strictly regulated approach to long-term planning of the life cycle of the oil or gas field, ORF / GRF assessment methods, field development plans and methods for reserves estimation, approaches to operations plans in the short term at most enterprises are far from ideal. In particular, the process of forming a program of production activities for the year and, especially, the month usually is not optimal, but consensus based. This is due to the fact that different departments responsible for development of a field, artificial lifting, gathering system sustainability plan their activities independently of each other, usually using their own planning tools, mostly implemented in a form of various spreadsheets in MS Excel format. Due to a large number of iterations of joint coordination, activities program at the beginning of each month is the most effective only from the point of view of compatibility of activities, priority of their implementation and responsible executors.

Nevertheless, the realities of the operation of any field are constantly making their own adjustments - these are unscheduled shutdowns of wells for various reasons, shifting the deadlines for performance of work, reducing budgets, changing production plans and much more. All of these changes lead to the fact that the activities program should be updated on a daily basis, both due to unscheduled situations and failures, and because of the identification of new activities for inclusion into activities program. Also, there are common problems with the goal setting - the investment departments are not always clear about the choice of activities proposed by production team, and vise versa - production team do not fully understand the feasibility of certain limitation related to the economy of projects. This leads to the formation of inefficient activities plans, which, moreover, quickly lose relevance and, due to the complexity of the reconciliation process, are not updated with the required frequency.

One of the well-proven approaches aimed at minimizing the above-mentioned problems is formation of multidisciplinary teams of specialists of various profiles who form an action plan together, saving considerable time for information exchange between departments. Such groups form the so-called "integrated operations centers," the effectiveness of which has been repeatedly confirmed both in Russia and abroad. One of the key factors in the effectiveness of such groups is how successfully the enterprise managed to create a unified information environment for joint work of specialists. In addition to the classical tools, in the form of specialized engineering software, modern information technologies such as Big Data processing and Machine Learning can enhance the productivity of integrated operations centers, which allow a considerable part of a routine work of specialists to be shifted to information systems.

The Production Management System described in this article is the realization of such a unified information environment for a multidisciplinary team of specialists responsible for planning activities at the hydrocarbon field.

Deming cycle in the management of oil production processes

As a fundamental idea for System, the concept of Deming Cycle was adopted, which, in combination with Big Data processing technologies, Machine Learning and proven methods of assessing the effectiveness of geological and technical measures and activities related to wells and gathering system, made it possible to create a self-learning system, the effectiveness of which increases as it is used.

Deming cycle (Repin, Eliferov 2008.) (Fig. 1), also known as the PDCA cycle ("Plan-Do-Check-Act") is a cyclically repeated decision-making process, widely used in quality management and business process optimization. Also, is known as "Deming Cycle," "Shewhart cycle," "Deming Wheel," "Plan-Do-Study-

Act," and "Deming-Shuhart Principle". The PDCA methodology is an algorithm for a manager to manage the business process and achieve its goals, which implies continuous improvement of the process itself.

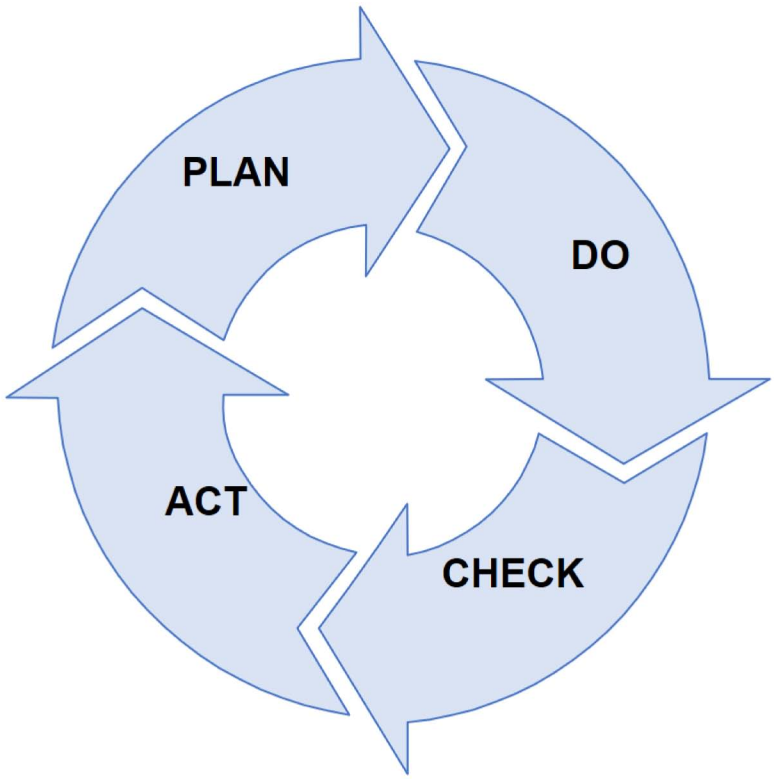

Figure 1—The Deming Cycle

Let's take a closer look at each of the steps in the cycle that begins with planning:

(P) Plan
Establishment of intermediate goals and sub-processes necessary to achieve the objectives of the main business process. Planning activities to achieve the goals of the process and meet its consumer (both external and internal, depending on the process). Planning allocation of necessary resources.

(D) Do
Perform the planned work of the previous step.

(C) Check
Collect information and evaluate the results achieved on the basis of key performance indicators (KPI). Identify and analyze deviations, identify the causes of deviations.

(A) Act
Take measures to eliminate the causes of deviations from the planned result, change in planning and allocation of resources in order to improve the efficiency of the process. Adjustment of planned key performance indicators (KPI).

In System under consideration, Deming Cycle is applied in the annex to the management of hydrocarbon production processes, namely, to solve the complex tasks of managing production, which includes:

- daily analysis of the operation of all production facilities of the oil and gas producing enterprise with the issuance of candidate activities for optimization;

- the process of coordinating the measures proposed by the System;
- automatic scheduling of the timing and order of implementation of activities, including the appointment of responsible executors;
- Calculation of the relevant production profile on a high-speed, daily auto-adaptive integrated model;
- monitoring the implementation of agreed activities.

By analogy with the steps of Deming Cycle, System consists of four main modules (Fig. 2): Integrated Analysis, Integrated Modeling, Integrated Planning and Monitoring. Also, there is a Master Data module, necessary for the operation of each of the modules.

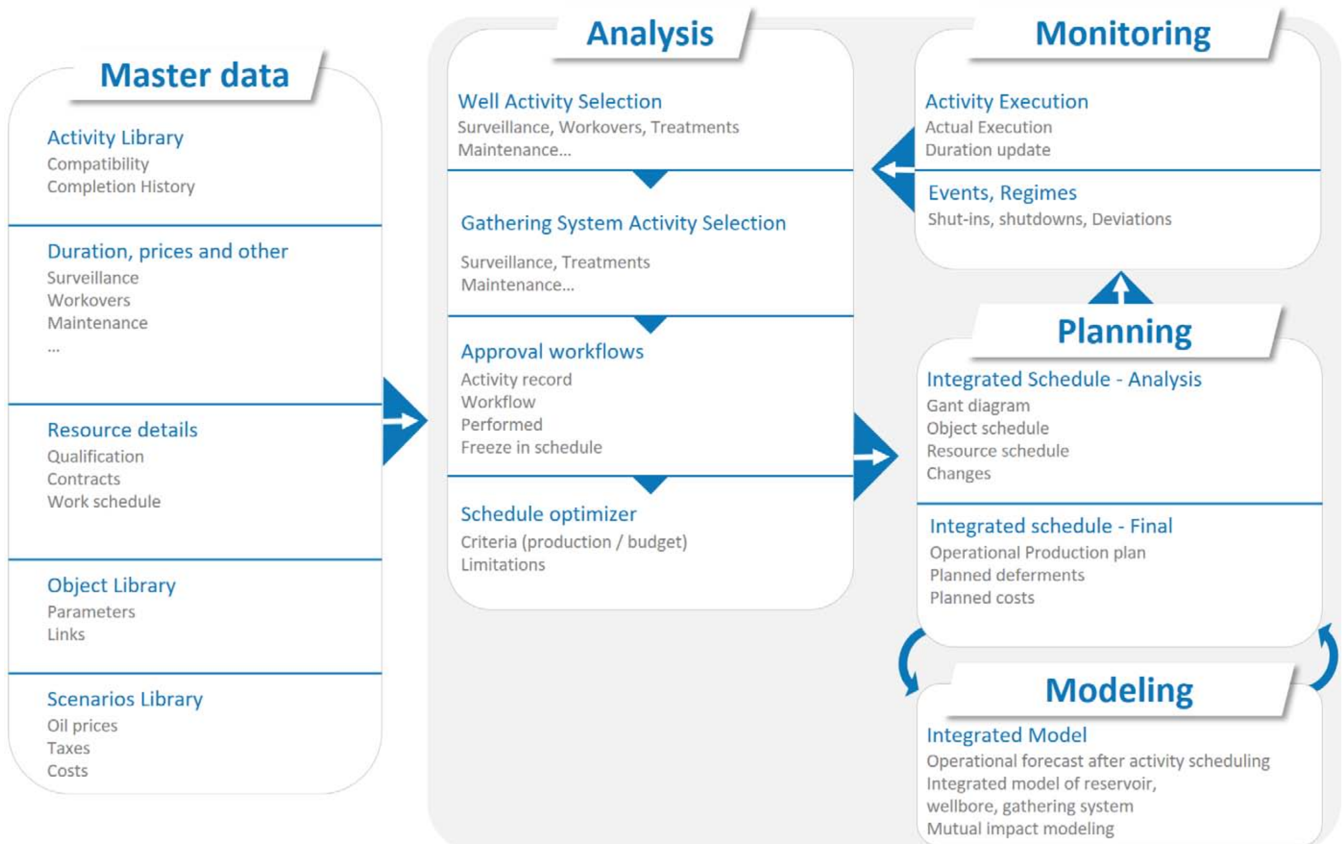

Figure 2—Scheme of system modules interaction

Let us to consider the functions of each of the modules in details.

Modules of the Production Management System

Integrated analysis module

The module is intended for selection of activities that impact production, i.e., that generate scope of activities used by the integrated plan in order to achieve the target production levels.

Main module functions:

- Calculation of remaining reserves, gathering and injection system potentials

- Automatic selection of WI with account for field development analysis, field-geological analysis, structural and technological analysis, previous experience, economic and risk analysis
- Construction of forecast production levels based on the result of WI with a forecast increment, basic production level return curve, effect duration, economics and risks
- Generation of report on justification of WI containing geological, development, economics sections
- Maintenance of boundary parameter values (technological potential, minimum allowed mode) of operation modes of gathering, injection, power supply network facilities
- Identification of bottle necks and suboptimal modes in gathering and injection system that cause substantial backpressure in the system
- Selection of activities for gathering system including scheduled maintenance and reconstruction and routine pipeline treatment procedures
- Selection of candidates for maintenance, treatment and well servicing based on component degradation and failure prediction
- Examination of all wells of the well stock to check if the current downhole pumping equipment is operated in the optimum mode, providing recommendations on the optimum equipment and its operation mode
- Analysis of sufficiency of the available surveys and selection of a minimum required set of surveys
- Analysis of opportunity costs – in case a recommended activity is not chosen, there is probability X that additional costs in the amount of Y thousand rubles will be incurred in the next month
- Optimization of field development – selection of activities for switching a well to injection, drilling, well reactivation
- Justification of production increment forecast, the need for implementation of WI, absence of limitations on implementation of WI
- Visualization of diagrams, field development maps, well design, applying benchmarking analysis to field development and operation parameters
- Training of the system, both interactive – by a user - and automatic – based on the analysis of implemented activities

To form a complete representation of the functional block possibilities, below (Fig. 3) shows the sequence of steps to be performed.

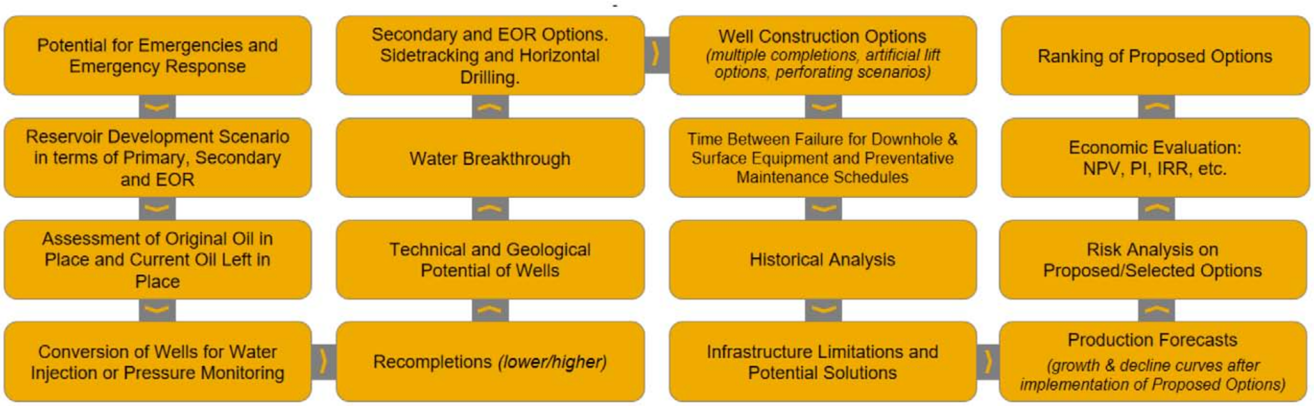

Figure 3—Integrated Analysis Sequence

Intergrated modeling module

The module is designed for modeling of fluid flow processes within the system "reservoir - near-wellbore zone – well - gathering and injection systems". The module also includes PVT and resource-economic models (Fig. 4).

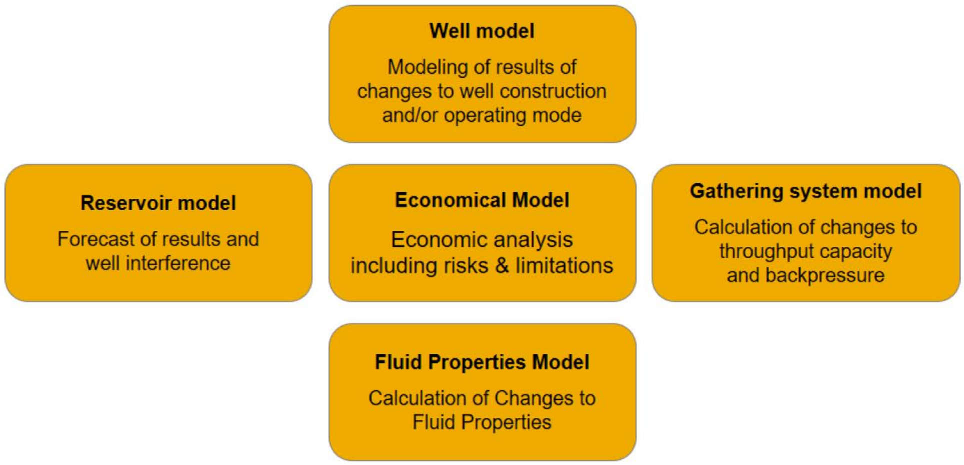

Figure 4—Elements of integrated engineering model

Main module functions:

- Analysis of the volume of survey data and measurements available for the modeling objects
- Selection of candidates for surveys to ensure the required modeling accuracy;
- Registration of the fact that a survey has been carried out after survey results are entered into the system;
- Forecast of oil production levels and production losses for the assets and for the company;
- Fast-track (daily, situational) forecast of oil production levels and production losses for one month;
- Calculation of production volumes with account for oil properties, interference within the reservoir and gathering and injection systems
- Modeling of switch-offs, switch-ons of the segments of gathering and injection systems
- Economic model that allows to apply conditions to the model components (example: tax vs. production level relationship)
- Modeling of downhole pumping equipment change out
- Modeling of well shut-in/start-up
- Modeling of putting a new well to production, including horizontal wells
- Modeling of conversion of a well to injection
- Modeling of well recompletion
- Modeling of options of WI
- Construction and/or import of a reservoir pressure map
- Construction and/or import of oil saturation maps
- Data import from standard reservoir simulating software

- Fluid flow maps and flow path maps construction
- Analysis and identification of well geometry when selection of downhole pumping equipment
- Calculation of the temperature model at nodes of the gathering system
- Determination of specific gravity of liquid-gas mixture (with account for PVT correlations)
- Determination of natural gas separation
- Calculation of a simulation model (with account for multiphase flow correlation)
- Construction of an artificial lift system model (depending on operation mode of an ESP, SRP, PCP, sucker-rod screw pump, etc.)
- Considerations of additional features for each operation mode
- Gathering system backpressure calculation based on initial flowrates with regard to pipeline system topology, diameters and hydraulic resistances of pipes and valves, vertical profiles and change of flow regimes. After gathering system calculation, wellhead pressures with account for backpressure are calculated.

Intergated planning module

The module is intended for maintenance of strategic, medium-term and annual plans and generation of monthly, operational plans of activities at the asset (Fig. 5). In such a way, this module can be used for solving of both operational and investment planning tasks.

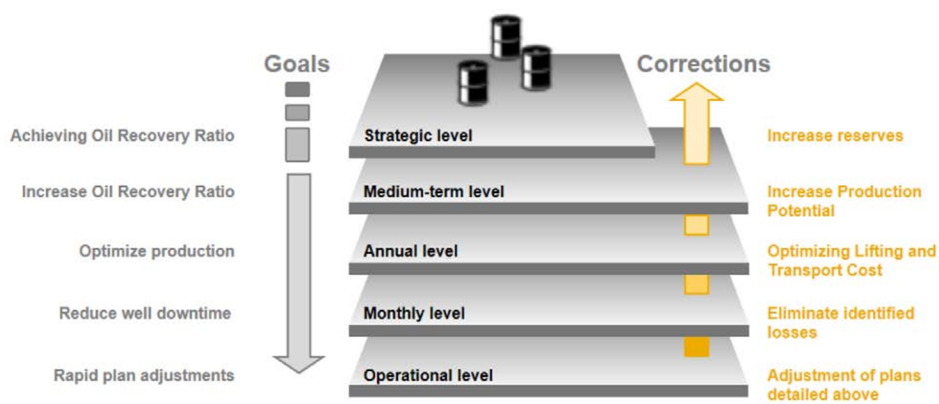

Figure 5—Elaboration and adjustments of targets

Main module functions:

- Downloading and maintenance of strategic and medium-term plans from development plans and available long-term planning tools;
- Downloading and maintenance of strategic and medium-term planning of a user investment plan;
- Maintenance of the catalog of candidate activities based on automatically selected and manually entered ones. Approval of catalog activities.
- Annual plan generation for all the activity types;
- Generation of a monthly plan for all the activity types;
- Capability of automatic generation of the integrated plan in the form of a common network schedule with account for targets, as well as resource, budget and other limitations:

  - Execution of oil production and custody transfer plan
  - Minimization of the required budget
  - Optimization of well start up/shut-in
  - Minimization of deferments
  - Compatibility of activities
  - Scheduled activities
  - External and fixed activities (an activity scheduled for a specific facility on a certain date)
  - Budgets, contractual commitments, crew specialization, availability of equipment
  - Applying an integrated model in order to forecast production levels and regimes, accounting for interferences of activities with one another on the levels of reservoir, well and pipeline system in the process of automatic plan optimization;
- Automatic generation of production profile according to a common network schedule;
- Capability to perform manual planning of activities at facilities and appoint crews to do the job;
- Capability to perform a manual adjustment of the integrated plan with its rescheduling;
- Automatic adjustment of the integrated plan after the data on actual deviations is received;
- Filtering of the integrated plan into functional plans;
- Approval of functional plans;
- Calculation of scheduled oil deferments by well, field, etc.;
- Capability to generate several integrated plan options;
- Decomposition of targets from strategic horizon through medium-term plans down to annual and monthly horizons;
- Generation of all the required scheduled PM and other similar activities;
- Resolving direct and resource conflicts during integrated planning;
- Estimation of a budget required in order to meet a target goal;
- Planning with account for statistic operating factor;
- Display of plan/actual execution of activities, production levels, deferments;
- Generation of plan outcome figures for a month, year – number of activities by their types and kinds, budget of their implementation, resource engagement;
- Approval of outcome figures of the integrated plan;
- Export of the integrated plan to MS Excel and MS Project;
- Generation of a pack of standardized reports.

To form a complete representation of the functional block possibilities, below (Fig. 6) shows the sequence of steps to be performed.

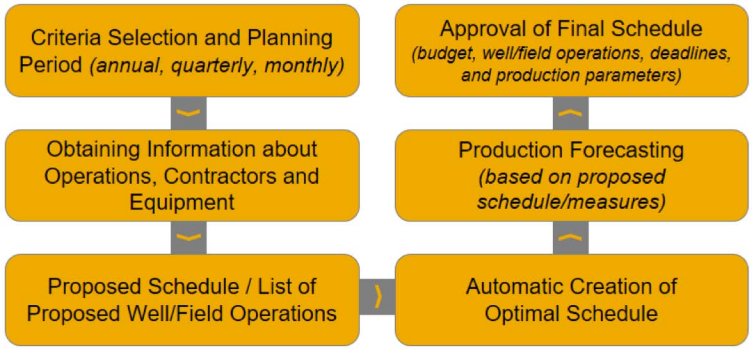

Figure 6—Integrated Planning Sequence

Monitoring module

The module is intended for collection of telemetry data and asset events that impact production; for monitoring of parameters, trend forecast of parameter overreach of corridors of allowable values, launch of business scenarios of response to deviations, events.

Main module functions:

- Online acquisition of telemetry system parameters for gathering, injection facilities and networks, wells, power supply facilities
- Acquisition of activities execution parameters from accounting systems (in case there is none in place – introduction into the system of actual information on events)
- Display of events, objects, actual, plan, forecast at multilayered interactive maps, mnemonic diagrams of facilities and wells, graph widgets, spread sheets
- Generation of an event on parameter overreach of the corridor of allowed values
- Receipt and processing of forecast of a value overreach of the corridor, forecasted date and time of probable overreach
- Launch and optimization of business scenarios by events with generation of requests
- Notification of events (email, SMS, automatic call)
- Monitoring of relocation schedule of crews, display of actual vs. planned schedule execution
- Acquisition and display of forecasted production levels, production losses and potentials
- Calculation of execution of planning horizon targets
  - Production
  - NPV
  - Budget disbursement
  - Execution of operational program (drilling, WI, surveys, etc.)
- Monitoring and forecast of operating factor by months, shops, fields
- Monitoring of the number of emergency situations by months, shops, fields
- Monitoring and failure forecast of downhole pumping equipment, gathering and injection system

To form a complete representation of the functional block possibilities, below (Fig. 7) shows the sequence of steps to be performed.

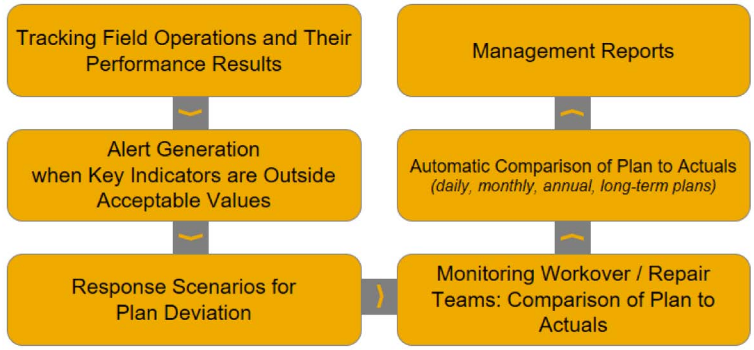

Figure 7—Monitoring Sequence

Approbation and results

The System was tested in one of the leading oil producing Company on the territory of the Russian Federation. Despite of significant level of processes automation the Company saw strong potential from the system deployment in operational aspects related to planning and other activities. As a pilot object the oil and gas producing shop (OGPS) with well stock of 600 wells was selected. Taking into account significant functionality of the System it was decided to do the testing stage by stage.

Integrated planning was selected as a functionality for the first stage. Almost immediately it was identified that pilot object need to be reconsidered because of lower structural divisions of contractors in accordance with their contract obligations execute their activities on four OGPSs which are part of Central Despatch Office (CDO). Thus, activities planning on one OGPS would not allow to account activities of contractor's crews on others OGPSs. As a result the project was expanded on all four OGPS and «Center of Integrated Operations» was created on basis of CDO. The main task of the «Center of Integrated Operations» is operational planning and the System was used as a main operational activity planning tool on the level of CDO.

Creation of the «Center of Integrated Operations» results in revision of organizational structure and CDO staff responsibilities. In particular the role of Integrated Planning Engineer, which did not exist before, appeared. The biggest part of tasks related to operational planning for which Excel spreadsheets or isolated accounting systems were used before now were transferred into the System. It allowed to combine automatically crews schedule in different OGPSs the routine process that before System deployment was executed manually by specialists responsible for particular OGPS. The above mentioned fact is one of the evidences that specialists of the «Center of Integrated Operations» started to work in single information environment and plan operational activities on several divisions as well as plan different functional activities on a well or an object level for the purpose of their compatibility and deferment reduction.

In addition, the issues related to testing of Well Interventions recommended by the System appeared. The selected well stock was exploited with ESP and this is of course restricted the list of potential operational activities. For the purpose of more precise assessment of the System functionality, the oilfield with other types of artificial lift such as Rod Pump and Sucker-Rod Screw Pump was added. As a result, there were additionally engaged about 400 wells with different types of artificial lift.

The next issue that appeared during the System testing was the absence of required data in the external data sources, which were used by the Company. For instance, the data of the subsurface pumping equipment was located in different Excel spreadsheets of Production Technologists. To overcome the issue the architecture of the System was reconsidered. A meta-layer of the data was added (Fig. 8). The meta-layer allows to keep required for analysis data which does not exist in the company entire system.

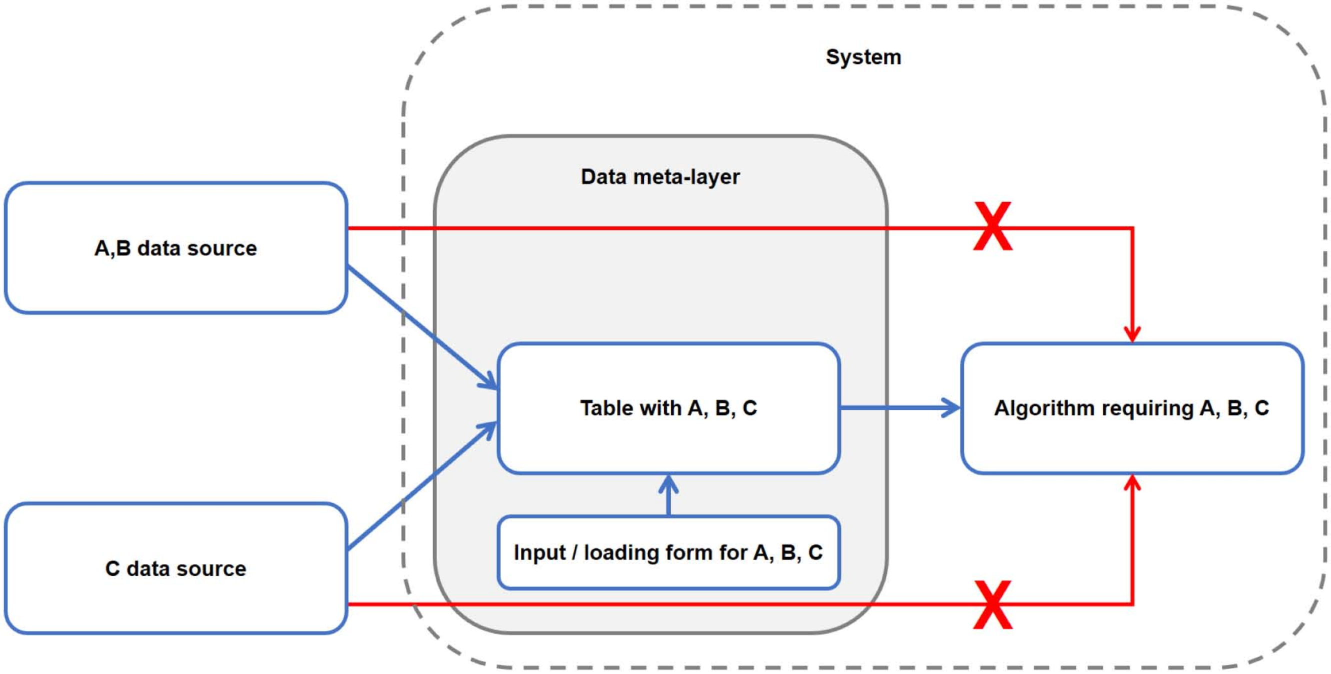

Figure 8—Schematic diagram of the data meta-layer

It allowed to make the System more flexible through opportunity of using of several systems that contain one category information as well use part of information which is entered or downloaded manually until the finish of the process of full integration with Company's accounting systems.

The important exercise was the assurance of data quality and its synchronization with data from different sources. Despite of significant level of automation of the above-mentioned tasks significant volume of data was transferred and verified manually. For instance, it relates to reference data entering about contractors, including cost of activities and list of available activities in accordance with contracts.

For these types of tasks the System Support Division was created. It allowed system developers to be focused on the System functionality development instead of solving issues related to data quality. On the later stages after accomplishment of the integration process with existing accounting systems the System Support Division started to enter and verify data directly in them instead of the System meta-layer. It also allowed to improve the quality of the external data which is used by Company for other purposes.

Algorithms implemented in the System are aimed to achieve the goals chosen for the analyzed period. This can be production maximization, cost cutting, NPV maximization, etc. It is also possible to assign target functions consisting of several indicators. In the process of analysis, the goals are decomposed with the target binding of the corresponding components of the objective function to each of the field objects.

Due to the need to process a large amount of data and carry out resource-intensive calculations related to the formation of an optimal plan of activities, SAP HANA database and its calculation optimization capabilities are used: "in-memory" technology, parallel computing, optimization of work with large arrays of information (Big Data processing technology).

To optimize the integrated plan, genetic and "greedy" optimization algorithms are used, as well as an "annealing simulation" algorithm. The combination of these algorithms makes it possible to minimize the number of iterations necessary to form the optimal activities plan from the point of view of the chosen objective function.

In the part of operational analysis of field development, the algorithm presented in Fig. 3 is used. The algorithm assumes the analysis of reserves, water cut, potentials, construction and overhaul period, site development, geological history, research and energy status. One of the key elements of the analysis is the analysis of workovers history (Retrospective Analysis). A retrospective analysis implies the analysis of each actually carried out geological and technical activities at least for the last 5 years. Namely: the determination of the behavior of liquid and oil, the analysis of artificial lift optimizations, the analysis of the reservoir model and the calculation of the actual technological efficiency of workovers. The second approach is based on the core technics of field development and evaluation of potentials analysis. The quantity and quality of the input data is also one of the key aspects in the selection of activities. To implement the functionality, regardless of the completeness of the availability of data, an approach based on the variability of the input data for analysis was implemented. Depending on the type of activities, three sets of necessary data are formed: Required, Desired and Additional (Fig. 9). Based on availability of these sets of data the System will evaluate the effect from the analyzed activity with different methods.

Figure 9—The data available for analysis determine which methods will be used in the calculations

As a coefficient informing about the completeness and quality of data for analysis, the "Risk coefficient" is used - "Risk coefficient". Coefficient takes into account not only the presence of a particular parameter, but also the quality of the data and their relevance (for example, time from the last measurements of the flowing level). For data processing, methods such as median filtering, winsorization, Kalman filter, ranges of allowable values, cross-validation of physically related parameters are used.

It is very important for the decision support systems, in addition to the risk analysis, also to have an instrument for decisions justification. For example, if the System recommends optimizing the well by changing the pump, it is necessary to understand why the System excludes other types of activities.

Based on the results of approbation of the System, we note the following features, which made the System implementation succesful:

- An open, extensible architecture, originally selected for the System, allowed the rapid addition / adjustment of approaches, regulations and methodologies which can be used.
- Integration with existing information systems instead of copying data to one more database not only allows significant savings on the IT infrastructure, but also improves the quality of information in these information systems by increasing their utilization.
- In-memory technology used for data storage makes it possible to recalculate over a thousand variants of operational plans on an integrated model for a fund of more than 600 wells a day and select the optimal plan of activities in the required time.
- Applying several techniques that require different amounts of data and counting with varying accuracy makes it possible to apply the System even in the case of a small amount of available data.

This also allows to determine what kind of information is missing, what additional measurements on the wells, or additional sensors, are required to improve the accuracy of calculations.

- The system actually duplicates the work of specialists when evaluating an activity, using the rules and restrictions described in the regulations. In case of disagreement of the expert with the received estimations, the System provides text explanations, explaining the taken decision by steps. This allows you to monitor results and promptly make adjustments, thereby speeding up the System training process.

Any planned activity is not only a technological effect that affects the field development, but also a budget that requires appropriate approval process. The System allows to describe in the visual format, without the involvement of programmers, the most complicated approval processes with reference to a specific activity and/or location (Fig. 10).

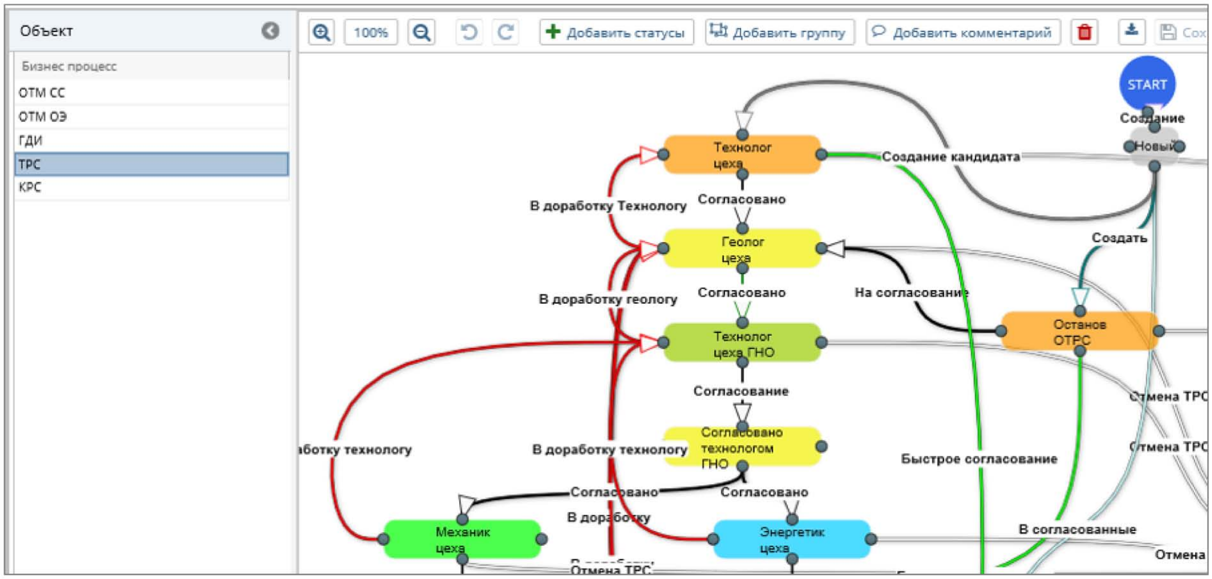

Figure 10—The description of the approval process does not require the involvement of programmers

Pilot project implemented at one of the Russian oil producing enterprises demonstrated a 2% decrease in operating costs on the tested fund, while unplanned deferments were reduced by more than 10%. Time, required to generate the plan was decreased by 120 times (forming a production plan, regimes and workovers schedule for a month took about 10 - 11 working days, in the System - 40 minutes). The time required for monitoring the implementation of the plan was reduced by 90 times (control of the plan execution took 1.5-2 hours per day, in the System - 1 minute). The time required for the analysis of one well decreased by 30 times (analysis took 30-60 minutes, in the System - 1 minute).

Conclusions

Thus, the effectiveness of the Deming Cycle concept in the design of self-learning information systems for managing oil production processes has been confirmed.

Considering the significant interest in the System from the gas producing companies, at the moment, the system is being supplemented with methods related to the operation of gas and condensate fields and gas gathering network objects, in particular, the composite fluid model and various methods associated with the processing of gas production facilities (hydrates and corrosion monitoring and prevention, choke diameters optimisation, etc.).

The existing model of constraints is one of the implementations of the currently popular choke-model, which will be visualized and, thus, expand the current functionality of the system, allowing the system to work on a number of new tasks.

Experience with both Russian and abroad companies has demonstrated the importance of effective integration of the System with existing accounting, ERP and SCADA systems used by the companies. The transition to the micro-service architecture, which is currently being implemented, will allow more flexible integration options and will speed up the process of the System deployment.

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