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Real-Time Reservoir Management from Data Acquisition Through Implementation: Closed-Loop Approach

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Abstract

The recent increase in deployment of intelligent field technologies is a clear sign of industry confidence in the ability of this new technology to deliver on its promises. Real-time enabling technologies, collaborative thinking and decision-making processes are three essential elements for real-time field management environment. This environment ensures that information from various sources is integrated leading to outcomes that meet business objectives.

With emphasis on Real-time Reservoir Management (RTRM), the petroleum industry is seeking more efficient management and production processes to improve the asset value throughout its various stages. RTRM can be described as constantly improving an objective function(s) that is dependent upon the concept of closed loop model.

In this paper, examples of various real-time optimization loops from Saudi Aramco fields will be presented to illustrate the above. These optimization loops have different cycle times depending on the process being optimized. To illustrate the concept, Haradh Increment-III development demonstrates a case study which is viewed as a milestone in real-time field management. The success of that development can be traced to the four elements of RTRM enabling technologies: geosteering, multilateral maximum reservoir wells, smart completions and I-Field. As a result of applying various real-time optimization loops, the Haradh Increment–III came on stream delivering 300 MBD five months ahead of schedule and has sustained better than expected performance.

Introduction:

The concept of real-time management and closed loops are not new (Figure -1), but are considerably new with regards to reservoir management. The fact that RTRM is a wide, growing and vibrant field, the petroleum industry is seeking more efficient management and production processes, to improve the quality and speed of decision throughout the various stages of an asset by the use of intelligent fields' technologies. A universal definition of RTRM has not yet been adopted by the oil and gas industry.

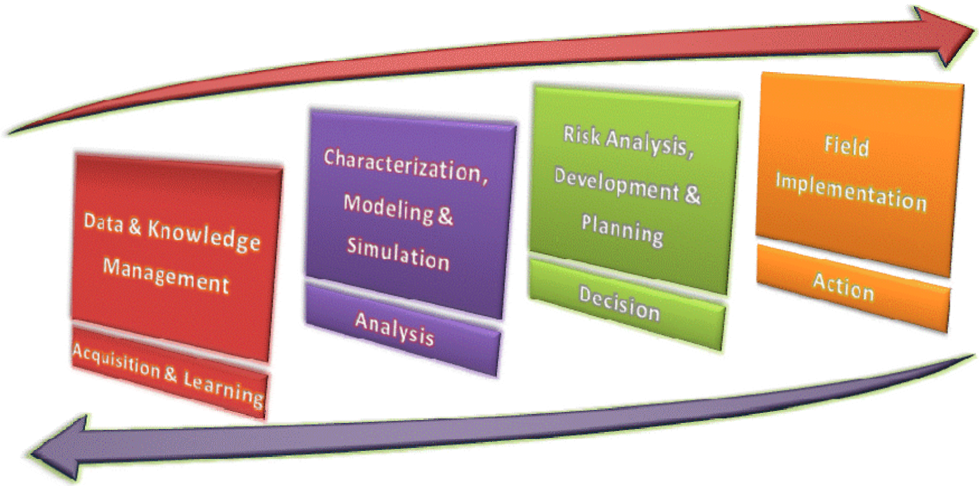

Figure -1: Real-time Management Process

For the purpose of this paper, RTRM can be described as constantly improving an objective function that describes value(s) from the asset. A company has to have an overriding objective such as reducing operating cost, sustaining production or maximizing recovery and asset value. For Saudi Aramco RTRM, the overriding objective is to ensure that short-term optimization supports long-term asset value; namely, sustaining production targets and maximizing ultimate recovery. These objectives can be accomplished by investing in enabling technologies, collaborative thinking and decision-making processes throughout the various stages of the asset life.

Many technologies and processes have been adopted into our business from downstream industry. Even though, some technologies, processes and environments have not matured yet, we still need to target them. Piloting such technologies provides unique learning opportunities and insights into their effectiveness and applications; hence, facilitates earlier good results and benefits. Closed loop RTRM makes sure that the full potential of various technologies is delivered. This advocated concept of closed loop RTRM is not by all means fully automated as will be illustrated in this paper.

RTRM is not about speeding up the flow of data; RTRM is about being able to monitor an asset continuously and react on time. Data will contribute to the increase of information and provide opportunities to develop new environments that will foster analysis, collaborative decision-making, optimization processes, and new automated responses. RTRM loops will come in different themes, depending on the role of the end-users and systems concerned. This section will discuss several RTRM closed loops case studies from the Haradh field.

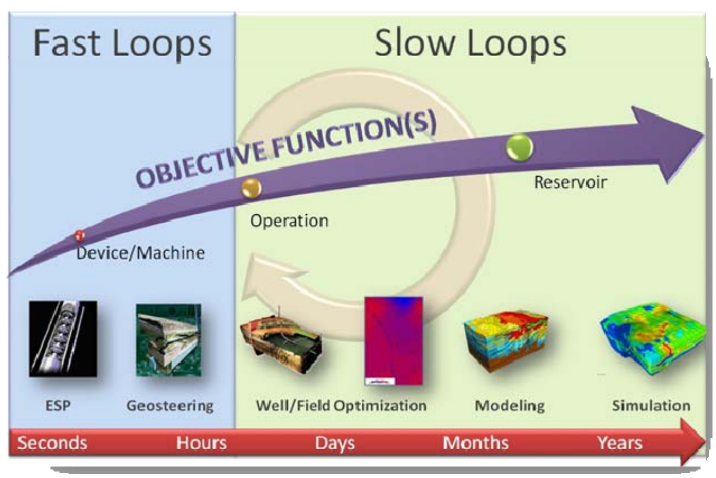

Figure -2: RTRM optimization loops have different cycle times depending on the process being optimized

RTRM Closed Loops Case Studies:

RTRM incorporates diverse objective functions because of the uniqueness of every case under evaluation. There is no "one-size-fits-all" approach. Given the best knowledge about the environment under evaluation, options are ranked according to the likelihood of meeting the objective that they fulfill. Things become more complex when more than one objective is available when determining the course of actions. The relative importance of the different objectives is taken into account in determining the overall order of the various options.

Figure -3: RTRM results in reducing the time to close some optimization loops.

The concept of RTRM can be applied to any environment under evaluation (i.e., an operation, a well, a reservoir, a process, etc). In RTRM, loops have different cycle times depending on the process being optimized. Slow loops for instance focus on an entire asset while fast loops main focus is different elements of the asset (i.e., an instrument, a function or a process). Figure-2 illustrates various RTRM optimization loops examples. These optimization loops have different cycle times depending on the process being optimized. With advancements in technologies and improvements in processes and expertise, it is reasonable to say that all loops durations will be smaller (Figure-3).

Any slow loop would have several embedded fast loops within it. Optimizing any of the embedded fast loops would be relatively simple but arguably would lead to optimizing an asset. Due to the fact that slow loops functions look over the entire asset optimization, the integration of its fast loops becomes necessary to realize their advantages. This section will discuss several successful implementations of RTRM.

Collaborative Thinking Environment:

Drilling operations have long been equipped with all kind of directional surveys and steering control capabilities. What makes them more useful is that they are now connected and available in realtime where all data are transmitted via satellite to remote geosteering centers. If there is any deviation from a plan or new information to be conveyed, current environment facilitates collaborative thinking, allows proactive assessment and promotes corrective measures. The Haradh Increment-III for instance was developed solely with Maximum Reservoir Contact (MRC) multilateral wells. One of the main elements contributing to the increment success was realtime geosteering operations. In these operations, a multidisciplinary team, consisting of reservoir engineers, geologists, directional drillers and drilling engineers improved the outcome. Figure-4 shows that such environments and technologies have shown their anticipated benefits, clearly reflected in the actual performance. The graph shows that over a span of four months, similar loops were closed at shorter time cycles (Figure-3).

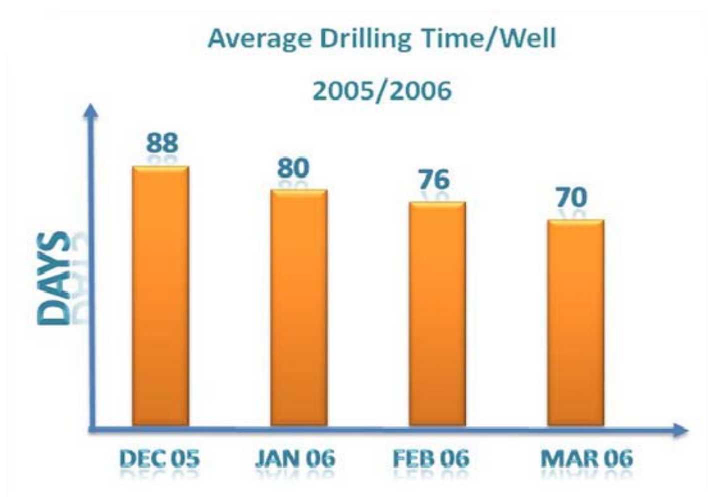

Figure -4: Geosteering technology significantly reduces drilling time. *Note:* Drilling was for a tri-lateral well with a triple ICV completion

Monitor, Manage and Maximize (MMM) the Value of an Asset

Haradh-A12 Well was completed in an area characterized by heterogeneity in reservoir rock properties, salinity and fluid movement[5]. The location dictated a completion that can capture realtime data, maximize control, optimize production, and increase value. The well was equipped with the infrastructure (i.e. smart completion and downhole gauges) that allows control and data transmission capabilities. The data were transmitted in real time for instantaneous analysis, multidiscipline decision and subsequent real-time implementation.

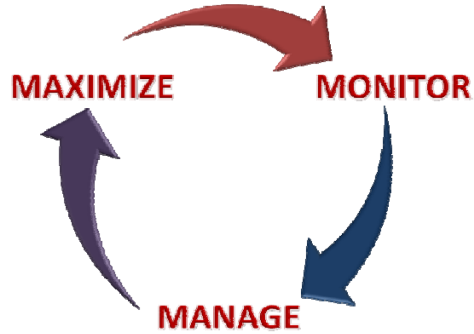

Figure-5: RTRM encloses realtime monitoring, management & maximizing the value of an asset

The objectives of the project were achieved when the anticipated performance was realized. The three main enablers of this optimization process were the abilities to monitor, manage and maximize asset value by multidiscipline teamwork, realtime control, realtime data acquisition and decision-making (Figure-5). Leveraged knowledge from Haradh-A12 and similar experiences provided an insight into RTRM implementation capabilities and potential benefits not only in individual well completions but in field development as well. The Haradh Increment-III, for instance, was developed with an infrastructure that allows real-time remote monitoring and controlling over the whole asset.

RTRM was evident when the 32 smart wells in the increment were remotely tested and their rates were optimized in accordance with the overall well and field strategy. The optimized performance was achieved by having team members from different disciplines, at different locations, collaborating, viewing the data, analyzing the data, making decisions, and implementing actions in realtime. Instantaneous optimizations were possible over the whole asset by integrating various realtime data from the individual reservoir, wells, flowlines and production facilities. As a result of these optimizations, the Haradh Increment-III has sustained an exceptional performance since start up.

Predictive, Preventive and Proactive (PPP) Modes

Typically in any development, it takes several months before anybody worries about any production data. Everybody will be busy celebrating the accomplishments or debugging facilities and other issues. Data will be the last thing to be thought of. What is so interesting in the Haradh Increment-III is that field data were transmitted in realtime from day one; in fact data were acquired even prior to production. During the pre-injection period and prior to putting the wells into production, reservoir pressure data were collected, analyzed and used to make subsequent decisions. During the pre-injection period, realtime reservoir pressure data were obtained from 12 wells across the field. This allowed generating dynamic isobaric maps that gave an insight into the evolution of the good pressure response over the reservoir. Another important observation was the quick pressure response in the northwest part of the field indicating potential of fracture corridors in the area which might have adverse impact on sweep efficiency and water encroachment. At the time, the RTRM environment predicted an accelerated water encroachment, prevented an imminent risk of losing potential from offset producers and proactively determined optimal injection and production rates of individual wells and region; hence, the optimization loop was closed (Figure-6)[6].

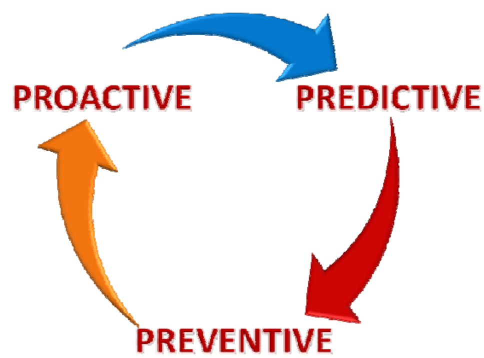

Figure-6: RTRM enables a work environment that works under predictive, preventive and proactive modes

Multiple Loops Integration for Optimal Asset Performance

As discussed in previous sections, RTRM loops come in different themes and most slow loops would consist of several fast loops. Multiple loops integration is a process where different loops fast and slow are incorporated to support both the short term and long term objectives of an asset (Figure-7).

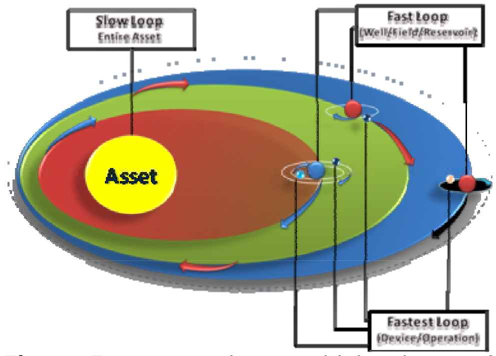

Figure-7: Integrating multiple loops for optimal asset performance

HRDH-A28, a trilateral MRC well, was tested at different surface choke setting to examine the contribution of individual laterals. Production data indicated potential cross flow between the laterals at certain choke settings. The choke was adjusted to a setting that eliminated the cross flow and the loop was closed by producing the well at that rate[1].

Subsequent comprehensive modeling of the well performance was done. The study included geological and petrophysical data along with a full field simulation model that incorporated near wellbore model. The model resulted in a very close match to laterals' contributions. The lessons learned of this experience were captured and the loop was close by understanding the flow mechanism in this well and by leveraging the knowledge into and designing subsequent simulation models, well completions and well and reservoir performance studies[4].

Data from multiple loops including and similar to the above were used as inputs into dual-porosity/dual-permeability models (DPDP). These models in conjunction with field dynamic data showed a better history match (Figure-8).

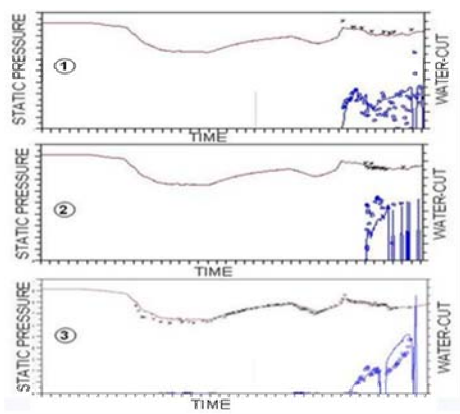

Figure-8: Results from multiple optimized loops in conjunction with production data led to better history match.

Prepare For the Unintended Consequences

It is expected that every change in management, strategy or work process has unforeseen positive or negative consequences. An unintended consequence might be a discovery of a new idea, an innovation, etc.; however, it can be an undesirable risk or complexity. Either way, cautious steps must be taken to identify an approach that is enabling rather than limiting[2&3]. Business as unusual is the environment we must accept; business as usual has in it considerable adverse consequences. The pace of the advances in technology, failure to take advantage of opportunities to improve business, all translate into less capability. We must adopt new strategies capable of identifying RMTM enabling technologies that do the following:

- Predict negative consequence
- Prevent or minimize their adverse impacts
- Take advantage of opportunities
- Facilitate quick change
- Accommodate modification of business environment

Upon analyzing the advantages and disadvantages of RTRM, and associated technologies, it is clear that the potential benefits far offset the potential costs associated with unintended consequences when an effective technology strategy is adopted. The Haradh Increment–III was selected to serve as a prototype to examine the nature of the changes necessitated by RTRM, and to test the environment and approach, for developing concepts and implementing changes. The new environment is supported by leaders across the board.

Due to the nature of the Haradh Increment-III reservoir, the original plan was to complete all wells as quad-laterals. The plan has changed upon realizing that the available technologies can target better quality reservoir rock and provide realtime assessment capabilities (positive consequences). Subsequent evaluation of the results led to modifying several well completions to tri-laterals with no adverse impact on potential.

As a result of applying various optimization loops during the development and operation of the Haradh Increment- III, our ambitious plans were exceeded. Haradh-III came on stream delivering 300 MBD five months ahead of schedule and has sustained better than expected performance.

Conclusion

The success of RTRM depends to a large extent upon the ability to coordinate activities to achieve synchronized operations and to be able to integrate all the loops to improve the overall asset value. The clear advancement in technology made it possible to provide more realtime reliable information to facilitate quicker and better decision. The examples illustrated in this paper have provided us with confidence in the ability of different technologies to deliver on their promises and we will continue to adopt and utilize them whenever applicable.

RTRM is increasingly becoming an information and collaboration environment organization. With this new transformation comes both risks and opportunities. A new business environment will be generated and a wide range of unintended consequences will evolve. Once those consequences are identified, they will be managed by adopting new processes and new ways of doing business will evolve. To succeed, we will always require new knowledge and we shall need more research.

The role of management has the greatest impact on demonstrating the importance of this new business environment by developing a vision and a mission that ensure continuous improvement in the entire asset value.

Acknowledgment

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