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A comprehensive literature review on closed-loop field development and management

Abouzar Mirzaei Paiaman

Introduction

In this edition, some highlights of the paper by Mirzaei-Paiaman et al. (2021) are presented. Closed-loop field development and management (CLFDM) is defined as a periodic update of an uncertain field model using the latest measurements (data assimilation), followed by production optimization aiming mainly at maximizing the field economic return. The paper provides a review of the concepts and methodologies in the CLFDM. It discusses different types of uncertainty encountered in field development and management. Then, concepts, components, and elements of CLFDM are presented. It also discusses different methodologies for data assimilation, followed by explaining a hierarchy of decision variables for production optimization including design variables (G1), life-cycle control rules (G2L), short-term controls (G2S), and revitalization variables (G3). The paper gives explanations for the use of closed-loop in both the development and management phases of a field project. In addition, methodologies for production optimization are discussed. Afterwards, objective functions for production optimization are presented, followed by the description of concepts and different approaches for selecting representative models. This paper also highlights the need for a standardized stepwise approach to apply the CLFDM.

Uncertainty in field development and management

A classification of uncertainties in field development and management is presented (Figure 1). Geological uncertainties have been studied well and constitute a large portion of the previous CLFDM studies. Reservoir engineering and information reliability uncertainties have also been studied but not as much as the geological uncertainties. Incorporation of other types of uncertainties and simultaneously accounting for multiple types of uncertainties are worthy of future research.

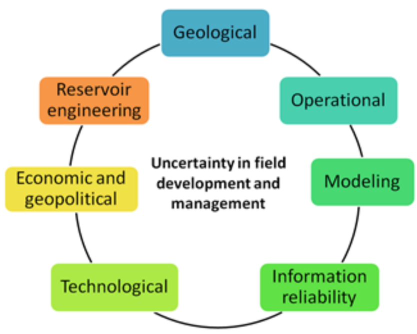

***Figure 1**: Types of uncertainty in field development and management*

CLFDM components

We describe closed-loop as a four-component process, in which each cycle contains the following actions (Figure 2).

1. Measurement: acquiring new information;
2. Data assimilation: updating uncertain field simulation models;
3. Production optimization and decision-making: selection of an optimal production strategy;
4. Implementation: operating the field with the selected production strategy.

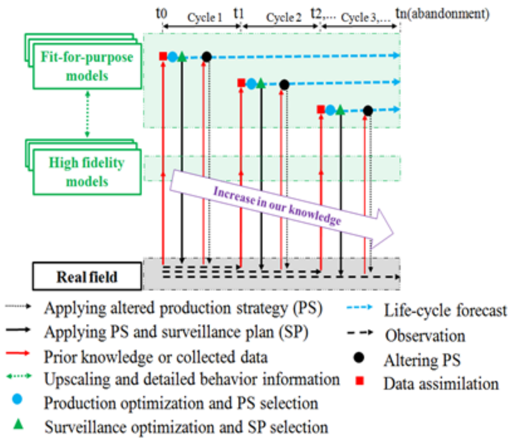

***Figure 2**: CLFDM and its elements. The readers are referred to the original paper for details.*

Data assimilation

Different approaches have been used for data assimilation, as follows:

1. Starting with an ensemble of models but updating the parameters of only one model to match the field responses.
2. Adjusting and updating parameters of all models to match the history data. This method has been widely used in the previous closed-loop studies
3. Iterative procedures of uncertainty reduction to find the best fitting models.

Data assimilation approaches that update all models, or find the best fitting models resulted in a better consideration of uncertainties in the decision-making process, since they provide an ensemble of models to the production optimization. Furthermore, as most of the previous works have updated all the models, more studies on the approach that finds the best fitting models can be subject for future works.

Closed-loop in different phases of a field project

In the literature, the terms CLFD and CLRM have been widely used to represent closed-loop processes corresponding to the development and management phase, respectively. In these acronyms, 'F' stands for the field, 'R' reservoir, 'D' development, and 'M' management. As field is a general name containing all components of a production system including reservoir(s), wellbores, surface gathering/injection networks, and surface facilities, it should be distinguished from reservoir. Thus, the terms CLRD and CLRM may better suite when a reservoir is not integrated with wells and surface facilities in modeling studies. A more general term CLRDM can account for both phases in such context. Once such integrated modeling is performed, then the terms CLFD and CLFM may fit the problem statement better. Accordingly, the general term CLFDM can be regarded as a broader category containing closed-

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loop activities in both development and management phases of a field. Furthermore, as field is more general than reservoir, CLFD, CLFM and CLFDM may describe CLRD, CLRM and CLRDM, as well.

Production optimization and decision-making

An optimized production strategy is selected through optimizing a set of decision variables by maximizing or minimizing an objective function(s). Depending on the outcome of data assimilation, several types of optimization can be defined:

1. Nominal optimization on a single model
2. Ensemble nominal optimization based on a single model but on an entire ensemble of models
3. RM nominal optimization (or extended nominal optimization) based on a single model but on a set of representative models (RM)
4. Robust optimization on an entire ensemble of models
5. Robust optimization on a set of representative models (i.e., RM robust optimization)

To take advantages of both nominal and robust optimization, we recommend simultaneous use of these two approaches in the decision-making process if time and resources allow.

Representative models

High computational burden associated with a large number of simulations can be reduced through use of representative models. Representative models should be selected in the way that they represent the uncertain characteristics of the original large population of models and also be free of optimistic and pessimistic bias. A schematic example of representativeness is shown in Figure 3, where the NPV risk curves of a few selected models cover fairly well the wide distribution of NPV risk curves of an ensemble. If such representativeness is also seen for risk curves of other performance metrics, then the selected models can be regarded as representative models for the problem. Cross-plots of performance metrics can also be included in this workflow.

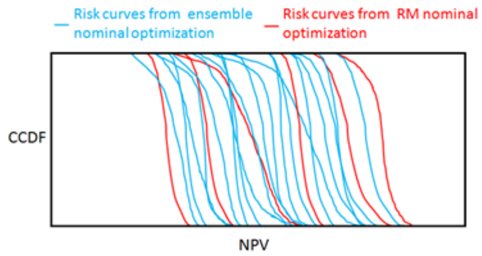

***Figure 3**: A schematic example of the concept of representative models for RM nominal optimization.*

If by any inexpensive means, one could select a small set of models such that when undergoing RM robust optimization yields an optimal solution similar to the optimal solution obtained from the robust optimization of the original ensemble, models of this set will be representative models for the problem.

Selection of representative models

Literature hosts many techniques for selection of representative models. Generally, these techniques can be divided into three categories, as follows.

1. Clustering-based techniques: These techniques try to find representative models by clustering continuous uncertain properties of an available ensemble.
2. Simulation-based techniques: These techniques are based on flow performance metrics of all models generated via simulation of a base-case production strategy.
3. Combination techniques: These techniques try to combine the two above approaches, and select representative models by production performance metrics simulated under a base-case production strategy, plus considering uncertain properties of an original ensemble of models.

We recommend the use of flow simulation techniques in selection of representative models to check whether the selected models represent the performance metrics of the entire. The selected models should also reflect the wide range of uncertain variables in the ensemble.

A stepwise standardized methodology for CLFDM

CLFDM needs to be performed following a workflow that incorporates all the necessary steps in an organized form. We recommend the use of the 12-step methodology for decision analysis in CLFDM by Schiozer et al. (2019).

Concluding remarks

Although the literature associated with data assimilation and production optimization is very extensive, CLFDM has received a lesser attention and was the subject of this paper. We presented a comprehensive review on CLFDM and established a unified concept definition, notations and workflow for doing closed-loop.

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