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Allocation system setup optimization in a cost-benefit perspective

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ABSTRACT

Allocation of hydrocarbons to their original production sources, also known as hydrocarbon accounting, is a key factor for the distribution of costs, revenues and taxes between interested parties in field development and production of oil and gas. When developing an allocation system, the allocation uncertainties in the system should be understood and accepted by all involved parties. Furthermore, the implemented allocation system should be cost efficient and practical to operate. One of the pivotal design questions for such an allocation system is the choice of measurement uncertainty of the individual metering stations comprizing the system. In this paper, we device a framework for allocation system modeling that allows for an algorithmic solution to the problem of optimizing the allocation system setup, i.e., choosing the right meter with the right uncertainty at the right place. This includes balancing the risk associated with misallocation due to measurement uncertainty against the cost of realizing the system. The presented framework makes use of a combination of optimization and ISO *Guide to the Expression of Uncertainty in Measurement (ISO GUM)* compliant Monte Carlo simulations. We illustrate the usefulness of our framework by applying it to example allocation systems with different allocation principles and production rates. We review the obtained results and provide a discussion of strengths and current limitations of the proposed approach.

The main contributions of this paper are 1) a novel framework for determining the optimal allocation system setup, 2) a flexible mathematical model for allocation systems, and 3) a description of a practical implementation of the framework as a coupling between Monte Carlo simulations and an optimization routine.

1. Introduction

Hydrocarbon production typically involves that hydrocarbons from a multitude of sources (wells, fields, etc.) are transported and processed in shared infrastructure. This inevitably yields commingling of different streams from different sources. These sources have different fluid compositions, different ownerships and may be subject to different taxation regimes. Eventually, the hydrocarbon stream is separated into oil, gas, and water and exported. The exported hydrocarbons then need to be distributed amongst the parties contributing to the hydrocarbon production in a fair and equitable manner, be it at well, field, or ownership level. This procedure is usually referred to as allocation, but also known as hydrocarbon accounting, product measurement and allocation, and production management and reporting (EI, 2012).

Allocation impacts several vital business aspects, most notably revenue and documentation of regulation compliance. Consequently, allocation receives a considerable amount of attention in the oil and gas industry. This can be seen in the existence of dedicated fora, e.g., the Norwegian Society for Oil and Gas Measurement (NFOGM) Hydrocarbon Management Workshop (2014 and 2016), and guidelines (e.g. EI, 2012), or recent publications, e.g., by Stockton (2009), Stockton and Wilson (2012), Frøysa (2014) and Skålvik (2016).

Allocation systems are typically designed based on contractual agreements between the parties involved, regulations, knowledge of the interconnection of different hydrocarbon streams (the topology of the system), and measurement points and concepts. The overall goal of such a system is to perform the allocation in adequately accurate and fair manner.

For a given allocation system, the uncertainties in the allocation calculation depends on the uncertainty of the installed equipment, i.e., the input uncertainties. High precizion measurement equipment reduces the risk of misallocation, but is usually more expensive than lower precision alternatives. How the individual measurement uncertainties affect the allocation uncertainty varies depending on system layout, production rates and the chosen allocation principles.

From the misallocation risk point of view, the best possible solution is to simply equip all measurement points with the best possible instrumentation. In the real world this is, however, not practical. This approach would yield considerable costs in terms of acquiring and installing the metering stations, as well as operational and maintenance costs. In the case where one of the streams contributes only marginally to the overall production rates, the difference between

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Nomenclature

$A \times B$	Cartesian product of sets A and B
c	objective function
$\tilde{c}$	combined cost/risk function
c_1	cost of the allocation system
$c_{1,i}$	cost of the *ith* metering station of the allocation system
c_2	cost associated with allocation uncertainty
$E(X_i)$	expectation of X_i
f	allocation function
J_f	Jacobian matrix of f
r_i	risk exposure due to misallocation to *ith* source
s	relative standard uncertainty
s^{opt}	optimal allocation setup, relative standard uncertainty
s_1	relative standard uncertainty of measurement
s_2	relative standard uncertainty of allocation
x	estimated/expected/measured inputs
x_0	fixed input
X	random vector of inputs
δ_{ij}	Kronecker delta
σ_f	standard uncertainty of f
$\sigma(X_i)$	standard uncertainty of X_i
$\sigma^*(X_i)$	relative standard uncertainty of X_i

choosing a high precision metering station and a less precise, and also less expensive, metering station might be minor in terms of the amount of possibly misallocated hydrocarbons. Hence, the additional cost of the high precision metering station might significantly exceed the value of the difference in misallocated hydrocarbons. Furthermore, there might be physical space limitations as to which metering stations, if any, that can be installed.

Balancing the risk related to allocation uncertainty and the cost related to achieving a certain total uncertainty is therefore an integral part of designing and modifying allocation systems (EI, 2012; Chan, 2014; Stockton, 2009). In this article we denote the examination of different allocation system setups with respect to their realization cost and allocation risk as cost-benefit analysis.

Integral part of a cost-benefit analysis of a allocation system is the quantification of allocation uncertainty following the ISO Guide to the Expression of Uncertainty in Measurement (ISO GUM) (ISO/IEC, 2008a). Performing such a cost-benefit analysis analytically and/or manually becomes rapidly unfeasible as the systems grow more complex, and can be considered prohibitive for the vast majority of real-life scenarios. Algorithmic solutions to this problem are therefore imperative.

It is important to stress that the aim of a cost-benefit analysis is rather to aid high-level decision making (multiphase meter versus conventional meter, calibration frequency, etc.) than a matter of fine-tuning the uncertainties of the individual metering stations. It is, e.g., unreasonable to expect to be able to purchase a metering station with the exact same uncertainty as suggested by such a cost-benefit analysis. Furthermore, there might also be other factors to be considered when choosing a vendor.

While the importance of cost-benefit considerations is widely recognized in the community (cf., e.g. EI, 2012; Stockton, 2009; Flølo, 2014), to the best of our knowledge, no algorithmic solution to the problem has been proposed until now. Automated optimization in the context of allocation is usually confined to production optimization, i.e., operational situation where the measurement uncertainties of the involved metering stations is to be considered fixed. Examples of such approaches can be found in Bieker et al. (2006), Cramer et al. (2011), Khishvand and Khamehchi (2012), Preveral et al. (2014) and Berg et al. (2015), to mention but a few.

The main contribution of this paper is a novel allocation system modelling framework for an algorithmic solution to the problem of determining the optimal metering station uncertainties for predefined metering points. In this context, optimality is defined from a cost-benefit perspective, i.e., the cost of a specific solution compared to the misallocation risk associated with it.

The remainder of this paper is structured as follows. First, we introduce the theoretical foundations of the framework and computational methods for allocation setup optimization. Subsequently, we discuss some aspects of a practical implementation of our framework and demonstrate its capabilities on selected example cases. Finally, we discuss strengths and limitations of the proposed approach and outline future work.

2. Theory and computational methods

In this section, we develop a mathematical model for the allocation system and its associated costs. We formulate the problem of finding an optimal allocation system setup as a minimization problem and discuss a computational method for solving this problem. Lastly, we give a short description of our implementation. A nomenclature can be found at the end of the paper.

2.1. Mathematical modelling

In essence, the defining property of an allocation system with n inputs and m distinct hydrocarbon sources is the way the allocation systems relates the inputs to the amount of hydrocarbons allocated to the individual sources. In this context, inputs are readings from installed measurement devices (e.g., single and multiphase flow rates from different measurement points) as well as other parameters used in the calculations (e.g., oil composition, oil shrinkage factor, etc.). Besides the values of these inputs, the system may also take their uncertainty into account (cf. uncertainty based allocation, EI (2012)). Mathematically speaking, we therefore assume the allocation system to be given as a function

$$\begin{aligned} f\colon\ & \mathbb{R}^n_{\geq 0} \times \mathbb{R}^n_{\geq 0} \to \mathbb{R}^m_{\geq 0} \\ & (x, s) \mapsto f(x, s) \end{aligned} \quad (1)$$

where $f(x, s)$ is a vector with m components, and its ith component is the quantity of hydrocarbon allocated to the ith hydrocarbon source in the system. The value of each component depends on the input x and its associated standard uncertainties s. The components of the vector x are the measured or estimated input parameters (flow rates, hydrocarbon compositions etc.). The components of the vector s are their respective measurement or estimation uncertainties. Each of the components of x can be viewed as a random variable X_l with expectation $E(X_l) = x_l$ and relative standard deviation s_l, corresponding to the uncertainty of the lth input parameter. Standard deviation is referred to as standard uncertainty in the ISO GUM context (ISO/IEC, 2008a). We adopt this nomenclature for the remainder of this article.

We assume that the cost of the allocation system is defined by the uncertainties of its inputs, i.e., the cost associated with being able to determine each and every input with a given uncertainty. Moreover, we introduce an additional “cost” associated with the uncertainty of the allocation system, which depends on the amount of hydrocarbons allocated to the individual sources and the uncertainty of this allocation. In mathematical terms, let