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Optimization Model to Analyse Optimal Development of Natural Gas Fields and Infrastructure

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Abstract

We present an optimization model for analysis of system development for natural gas fields, processing and transport infrastructure. In this paper we present our experience from performing analyses for the natural gas industry with the optimization model. We also present a model extension in the form of continuous investment decisions. This extension allows the capacity in pipelines, processing facilities and compressors to be determined within a given range by the model. We also give a partial model description along with a case example that demonstrates the importance of using continuous investment decisions when considering design in natural gas systems.

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1. Introduction

Thorough infrastructure design and investment analysis is crucial to the decision makers in the natural gas industry due to the large costs associated with production fields, processing facilities, compressor stations, pipelines and other infrastructure elements. The ability to value flexibility and identify bottlenecks in the system is also of importance due to the large value created by the production of natural gas. The decision maker needs to decide on which elements to invest in at what time and with what capacity, which gives a large combinatorial decision space that is almost impossible to explore by hand. Combinatorial optimization models are well suited to analyse such

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problems. The optimization model that we will use as a basis for our discussion in this paper is developed with the Norwegian Continental Shelf as a motivating case. The results and discussions will however be valid for other gas production systems. The Norwegian system consists of approximately 7800 km of subsea pipelines with large diameters operated at high pressure levels. Another important aspect of natural gas production and transportation is the multi-commodity characteristic of natural gas. The gas consists of several different components, such as methane, propane, butane, CO_2 and H_2S that contribute to the properties of the gas properties in different ways. These properties will influence the need for processing capacity and the possibilities for blending gas to meet quality specifications in markets. The optimization model that we discuss in this paper can be used for analysis of multi-commodity flows, but in this paper we will simplify the presentation by focusing on single-component flows.

An optimization model that has been used by both authorities and companies that invest in natural gas infrastructure is presented in [1]. The model we use in this paper, Ramona, is presented in more detail in [2]. It extends the model presented in [1] with more details on the operations of the network (such as pressure-flow modelling and gas quality). This way it can be used to analyse projects such as branch-offs and the trade-off between processing plants and blending of natural gas from different fields. The basis for the modelling of natural gas transport is given in [3] and [4].

The problem of designing offshore oil and gas infrastructure has received considerable attention over several years. Some early examples, mainly focusing on the development of reservoirs and wells of single fields, are [5] and [6]. [1], [7], [8], and [9] take a network perspective coordinating multiple fields. Several papers also model the influence of uncertainty, see for instance [10] on market uncertainty and [11] on uncertainty in reservoir properties. [12] use an equilibrium model for the investment planning, in contrast to most other papers that use mixed-integer linear or non-linear models. [13] limits the scope to the transportation network and describe the problem of optimal pipeline dimensioning when the network structure is given. Related problems are treated by [14] who discuss the problem of network expansion for a given transportation demand and [15] who combine network expansion and liquefied natural gas terminal location. There are two traditions for how to describe network capacity choices, while for instance [1], [13] and [15] model discrete capacities, [8] and [14] allow for a continuous capacity choice.

The main contribution of this paper is a presentation of experiences with using an optimization model for providing decision support on natural gas infrastructure design. We will also discuss a model extension which allows for continuous capacity investments in pipelines, processing facilities and compressor stations.

In the next section we will shortly describe the optimization model that we have used in our analyses, and give the continuous capacity extension formulation. In Section 3, we present a numerical example to illustrate the importance of using continuous capacity decisions for the investments. In Section 4 we discuss some of the experiences from real world applications of the model in general and the continuous formulation in particular. We conclude the paper in Section 5.

2. The optimization model

Ramona is a mixed-integer linear optimization model that includes both investment decisions and operational decisions. The level of detail in the operational decisions will vary with the availability of data and the size of the problems. Pressure-flow relationships, compressors, operation of processing facilities as well as multi-commodity flows are optional features in the model. The modelling of multi-commodity flows allows for inclusion of gas quality management also in the design decisions. For more details on this aspect, see [2] and [16].

The investment decisions are modelled as binary variables for deciding between different alternative investments as well as timing for the investments. Fields have predefined production profiles, but are given some flexibility to withhold production capacity to adjust to the available capacities in the rest of the network, see [1] for details. For pipeline and processing capacity we have two alternative model formulations. The first alternative has predefined discrete capacity choices selected with the binary investment variables. The other formulation has a continuous capacity choice within given bounds.