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"OPTIMIZATION METHODS FOR THE DESIGN AND PLANNING OF OFF-SHORE GAS FIELD INFRASTRUCTURES UNDER UNCERTAINTY"

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13. ABSTRACT (Maximum 200 words)
This reports addresses the problem of design and planning of an offshore gas-producing site with given a number of reserves of gas, or fields. Major sources of uncertainty that are considered for the unexplored fields are their sizes and deliverabilities for which discrete probability distribution functions are assumed to be given. The goal is to determine over a long time horizon (e.g. 10-20 years) investment decisions on the fields that should be exploited and on the infrastructure that needs to be set up for this purpose. Operational decisions relate to determining the production rates of the fields over time. The optimization objective that was selected is the maximization of the expected net present value of the project. The report describes novel multi-stage stochastic optimization algorithms that have the feature that the scenario trees are dependent on the design decisions. The first algorithm relies on an approximation strategy, while the second one relies on a branch and cut method based on a Lagrangean relaxation scheme. Results are presented for four examples that were developed in conjunction with ExxonMobil..

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SUMMARY

Oil and gas exploration and production is a unique industry with annual property acquisition, exploration and development costs of many billions of dollars. With such high investments and profits, it is not surprising that many decisions involve very large expenditures. Also, since projects are characterized by time horizons of 20-30 years, the investment decisions have long-term impact. For such capital intensive projects, there is a clear need for developing systematic optimization tools that can aid in the decision-making process. Since the industry deals with long-term contracts where the producer is obligated to deliver a certain minimum amount annually, a significant portion of the capital-intensive decisions are made early in the life of the project. At this stage, there is significant uncertainty regarding estimates of size and quality of reserves, future oil/gas prices and future demands. Hence, for optimization tools to be of greater value in these applications, it is necessary to take uncertainty into account.

In this report, we consider the optimal design and planning of gas production field infrastructures with uncertainty in the estimates of the size and quality of gas reserves. Specifically, we consider a given a number of fields. Some or all of these fields have to be drilled to extract gas. To drill each field, a dedicated well-platform has to be installed. The platforms have to be connected to each other by a network of pipelines. The gas is sent from the well-platforms through these pipelines to a production platform where the gas is compressed before being sent to the shore. The fields being considered are classified into fields that have reliable information, acquired through exploratory drilling and surveys done in the past. The rest of the fields have uncertainty in their size and the deliverability. Given these fields and a time horizon for the project, the objective is to maximize the expected net present value by deciding: (a) whether to install a well-platform at a field to exploit that field, and when, (b) which pipeline connections to make and when, (c) capacity for each well and production platforms, (d) whether to install a compressor at the production platform and when, (e) the production profile from each field. The goal is to develop computationally effective algorithms for these problems. Several examples are presented to illustrate the proposed methodology.

INTRODUCTION

Overall objectives

In this project the specific problem that we investigated was a new stochastic optimization model for the design and planning of an offshore gas-producing site with a number of reserves of gas, or fields. Major sources of uncertainty that were considered for the unexplored fields are their sizes and deliverabilities. We assume that discrete probability distribution functions for these uncertainties are given. The overall goal is then to determine over a long time horizon (e.g. 10-20 years) investment decisions on the fields that should be exploited and on the infrastructure that needs to be set up for this purpose. Operational decisions relate to determining the production rates of the fields over time. The optimization objective that was selected is the maximization of the expected net present value of the project.

Description of research project

An offshore gas production site has a number of reservoirs of gas, known as fields. The typical infrastructure at an offshore site includes well platforms (WPs), production platforms (PPs) and connecting pipelines, as shown in Figure 1.To extract gas from a field, a dedicated well platform (WP) has to be installed at the field. Each WP is connected to another WP, or to a production platform (PP), through pipelines. Gas produced at all WPs is sent to the PPs and from there to the shore through this network of pipelines. During an off-shore gas production project, investment and operation decisions have to be made. Investment decisions include selecting where and when to install the WPs and PPs, the capacities of these platforms, and the pipeline connections to be constructed. Operation decisions include determining the production profiles for the different fields over time.

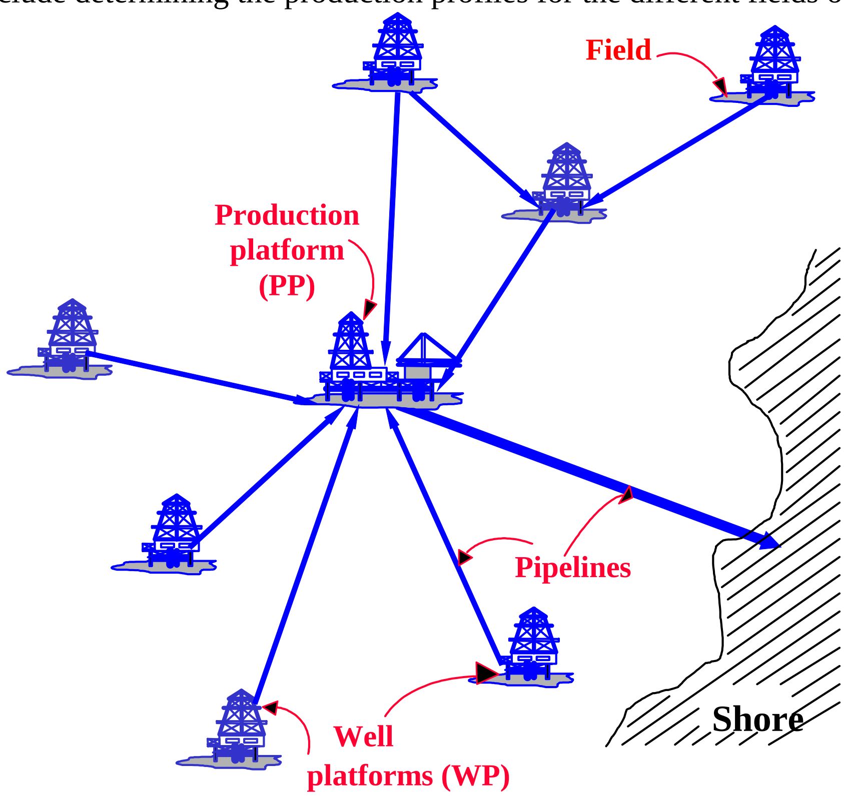

Figure 1. A typical offshore gas production site

To facilitate decision-making at the planning level, the project horizon is discretized into time periods and each of the above decisions have to be made for every period. Discrete decisions regarding which WPs, PPs and pipelines are to be installed, and when, are represented by binary (0-1) variables, while capacities of platforms and all operation related decisions are represented by continuous variables. This combination of discrete and continuous variables, along with the non-linear reservoir model that governs the gas production for a field leads to Mixed Integer Non-linear Programming (MINLP) models with the objective of maximizing or minimizing a specific value function. In this project, we have addressed the planning problem with uncertainty in the reservoir properties of the fields. We present a multistage stochastic programming model and solution strategy for planning the development of a multi-field offshore site under uncertainty in the sizes and initial deliverabilities of the fields, where investment and operational decisions have to be made. In view of the complexity introduced by the uncertainty, we will assume a linear reservoir model for each field, which leads to a Mixed Integer Linear Programming (MILP) model.

Rationale for undertaking the research project

Oil and gas exploration and production is a highly capital-intensive industry. As an example in the year 2001 the total earnings from oil and gas exploration and production for ExxonMobil were in excess of $10.4 billion. To maintain productivity that led to such high earnings, the company invested $7.9 billion in property acquisition, exploration and development during the year. (Exxon Mobil, 2001) [10]. Facilities required for offshore exploration and production often remain in operation over the entire life-span of the project, typically 10–30 years. With such high investments and profits, it is not surprising that many decisions involve very large expenditures. For instance, leasing a drilling rig typically costs $1 million per day and the waiting time to get one may be up to two years. Also, since projects are characterized by time horizons of 20-30 years, the investment decisions have long-term impact. For such capital intensive projects, there is a clear need for developing systematic optimization tools that can aid in the decision-making process.

Therefore, decisions regarding investment in these facilities affect the profitability of the entire project. Given the large potential profits and high investments in each project, there is significant interest in developing optimization models for planning in the oil and gas exploration and production industry. A major challenge lies in the fact that decision-makers in this industry have to contend with a great deal of uncertainty.

One of the most important sources of uncertainty is the quality of reserves. The existence of oil and gas at an offshore site is indicated by seismic surveys and preliminary exploration tests. However, the actual amount of oil or gas in these reserves, and the efficacy of extracting these remain largely uncertain until after the investments have been performed. Hence, the effect of these uncertainties must be taken into account when formulating the decision policy.

Projected benefit to gas consumers

The development of optimization tools like the one in this project can lead to significant reduction in the investment of gas oil exploration facilities, as well as a reduction in the effect of uncertainties in the exploration. This should translate to lower price of gas for consumers as well as more reliable gas supplies.