Development planning is extraordinarily complex due to many logistical, technological, regulatory and economic constraints.

Courtesy of EQT

Optimization engineering at EQT

In-house team supports better, faster decision-making at the largest producer of natural gas in the United States.

By Markus G. Drouven

Born in the Appalachian Basin and headquartered in Pittsburgh, Pa., for 130 years, EQT Corporation is the largest producer of natural gas in the United States. EQT's key operations include the exploration of productive natural gas deposits from shale formations, gas extraction through safe and efficient horizontal drilling technology, and gas transportation for delivery to market.

EQT supports nearly 950 employees and several thousand contractors throughout Pennsylvania, West Virginia and Ohio. The company owns or maintains drilling rights to more than 1 million acres of land in the Appalachian Basin, with approximately 680,000 net acres in the core Marcellus development area.

Inception of the Optimization Engineering Team

In early 2014, EQT entered into a research collaboration with the Center for Advanced Process Decision-making (CAPD) at Carnegie Mellon University (CMU) in Pittsburgh. The stated goal of the collaboration was to evaluate the potential of rigorous, mathematical optimization to promote low-cost

All About the Roundtable

The Roundtable consists of the institutional members of INFORMS with member company representatives typically the overall leader of O.R. activity. The Roundtable is composed of about 50 organizations that have demonstrated leadership in the application of O.R. and advanced analytics. The Roundtable culture is peer-to-peer, encouraging networking and sharing lessons learned among members.

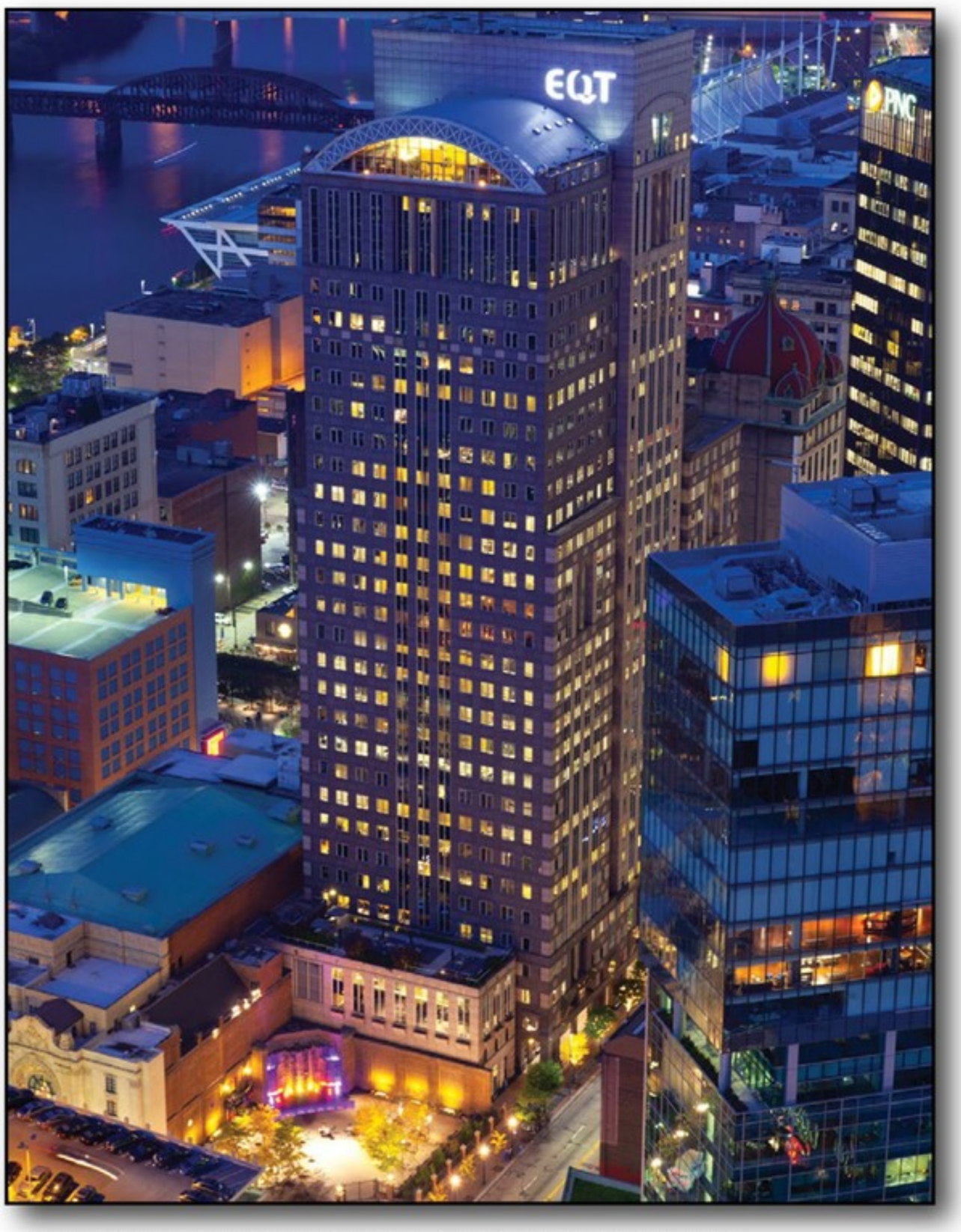
The Roundtable meets three times a year. Roundtable goals are to improve member organizations' OR/MS practice, help Roundtable representatives grow professionally and help the OR/MS profession to thrive. Further information is available at http://roundtable.informs.org.

The Roundtable also has an advisory responsibility to INFORMS leadership. According to its bylaws, "The Roundtable shall regularly share with INFORMS leadership and advise the INFORMS Board on its views, its suggested initiatives and its implementation plans on the important problems and opportunities facing operations research and the management sciences as a profession and on the ways in which INFORMS can deal proactively with those problems and opportunities." The Roundtable Board meets with the INFORMS Board each spring to discuss topics of mutual concern.

This series of articles aims to share with the INFORMS membership at large some information and insights into how O.R. is carried on in practice today

natural gas production from shale formations. A group of researchers within the CAPD, led by Professor Ignacio E. Grossmann, was tasked to study some of the most challenging aspects of shale gas development, and report back on any promising opportunities for mathematical modeling and optimization.

Over the course of five years, the research group at CMU produced nearly half a dozen publications that unanimously concluded that the opportunities for rigorous optimization in the shale industry were huge. Through real-world case studies and comprehensive lookbacks, the researchers showed that mathematical models could help upstream operators address a variety of important challenges, namely: a) deciding on where to focus drilling and fracturing activities, b) lowering water management costs by effectively coordinating water deliveries, and c) managing pressure profiles within pipeline networks. As a result of these findings, EQT decided to invest in prescriptive analytics in 2016 by forming the Optimization Engineering team.



EQT is the largest natural gas producer in the United States.

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The Optimization Engineering Philosophy at EQT

The newly formed team's mission was clear: support better and faster decision-making across the company by translating practical business and engineering problems into mathematical models and use these models along with rigorous optimization techniques to make specific recommendations for action. While this mission statement may seem straightforward at first, there are a few noteworthy differences compared to similar teams at other companies. Most importantly, the Optimization Engineering team at EQT is not a software development group. Rather than focusing on the development of commercial software-support products (now known as "applications"), the team's primary goal is to provide an in-house decision-support service. There are several reasons why this decision-support "service philosophy" is advantageous.

Optimization engineers gain valuable knowledge about the business and engineering problems they translate into mathematical models. The modeling process itself forces individuals to literally: a) define business or technical objective functions, b) identify restrictive constraints, and c) determine degrees of freedom in terms of decision variables. In developing, testing, validating and

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refining their models, optimization engineers at EQT develop an intricate understanding of the practical problems decision-makers face. Over time, this allows them to appreciate common operational bottlenecks, or recognize which actions lead to undesirable outcomes. Optimization engineers can then use this knowledge to evaluate different scenarios of interest with reasonably modified parameter settings or justified constraint flexibility to see what impact such changes can have on business objectives.

These insights can be invaluable to decision-makers who often do not have the time or available manpower to perform in-depth analysis. For precisely this reason, not every model that the Optimization Engineering team develops ends up being deployed as a software application. Instead, the team is generally willing and eager to maintain and operate selected models and provide decision-makers with specific and detailed recommendations for action.

Using Optimization Models for Development Planning

One of the challenges the Optimization Engineering team at EQT is currently addressing is shale gas development planning. Development planning describes the process of scheduling the key operations that are necessary to recover hydrocarbons from a shale reservoir. These operations include drilling, fracturing and "turn-in-line" activities that need to be performed in sequence to produce natural gas from a prospective shale well.

At EQT, development planning challenges are addressed by the Asset Development Engineering (ADE) group. This group's mission is to determine where, when and how many wells to develop over planning horizons ranging from one to five years so that the net present value across an entire operating area is maximized. The development planning challenge is extraordinarily complex due to many logistical, technological, regulatory and economic constraints. Due to the complexity of the development planning challenge, and its economic importance for EQT as a whole, the ADE group turned to the Optimization Engineering team to explore how mathematical models could be used for decision-support.

The Optimization Engineering team decided to study and address individual parts of the challenge step by step. Initially, the team designed a mixed-integer programming model that schedules the development of multiple wells on a single pad. Many upstream operators have the ability to drill up to 40 horizontal wells from just one pad. The single-pad planning model is therefore designed to consider individual well economics, and it produces a detailed development schedule that specifies precisely when each well should be drilled and completed over time.

Next, the Optimization Engineering team designed an optimization model that considers the development across multiple well pads within one interconnected pipeline capacity system. The single-system planning model addresses the more tactical development planning challenge of how to coordinate production from multiple well pads to best utilize available pipeline capacity. More recently, the team decided to tackle the fully expanded version of the development planning challenge by designing a multi-system planning model. This model simultaneously considers all of EQT's existing and prospective development areas, and identifies: a) where to focus future development activity, b) how many development resources (drilling rigs, fracturing crews) to procure, and c) how much downstream take-away capacity to secure. All three optimization models are developed such that the output from one model can easily be fed into another model. This allows for the effective solution of the overarching developing planning challenge at the operational, tactical and strategic levels.

All three models have been tested and applied to actual, prospective development projects, and rigorously solved for the proposed development strategy. The findings of this analysis were remarkable. The optimization results suggested that EQT should design its development schedules such that any available downstream pipeline capacity would be utilized as much as possible. In other words, the proposed drilling and fracturing schedules were driven predominantly by capacity utilization – even at the expense of developing marginally less-economic but readily available wells. Moreover, it became apparent that the optimization was very selective about which, and, more importantly, how many wells it would develop on any given pad.

Specifically, the results suggested that it did not always make economic sense to drill and complete all available wells on a pad at once. Instead, the proposed schedules were characterized by return-to-pad operations, for which only a few wells at a time are developed. Why use this strategy? Because developing a large number of wells at once takes a long time – up to a year or more. During this time, a pad is not producing any gas, and the company is not generating any revenue from the asset. In other words, EQT is not seeing any return on its investment for an extended period of time. By only developing a small batch of wells at time (typically 3-4 wells), the onset of production volumes is drastically accelerated, and EQT can generate a much earlier return on its investment.

Naturally, this development strategy requires frequent mobilization of development resources (such as drilling rigs and completion crews) – for which the associated expenses are explicitly considered within the respective optimization models. However, a comprehensive post-optimization analysis confirmed that, considering the time value of money, selective development strategies characterized by near-perfect capacity utilization and frequent return-to-pad operations can greatly improve development economics by millions of dollars. These findings have had a profound impact on development planning at EQT, and they illustrate how the Optimization Engineering team is supporting central decision-makers within the organization.

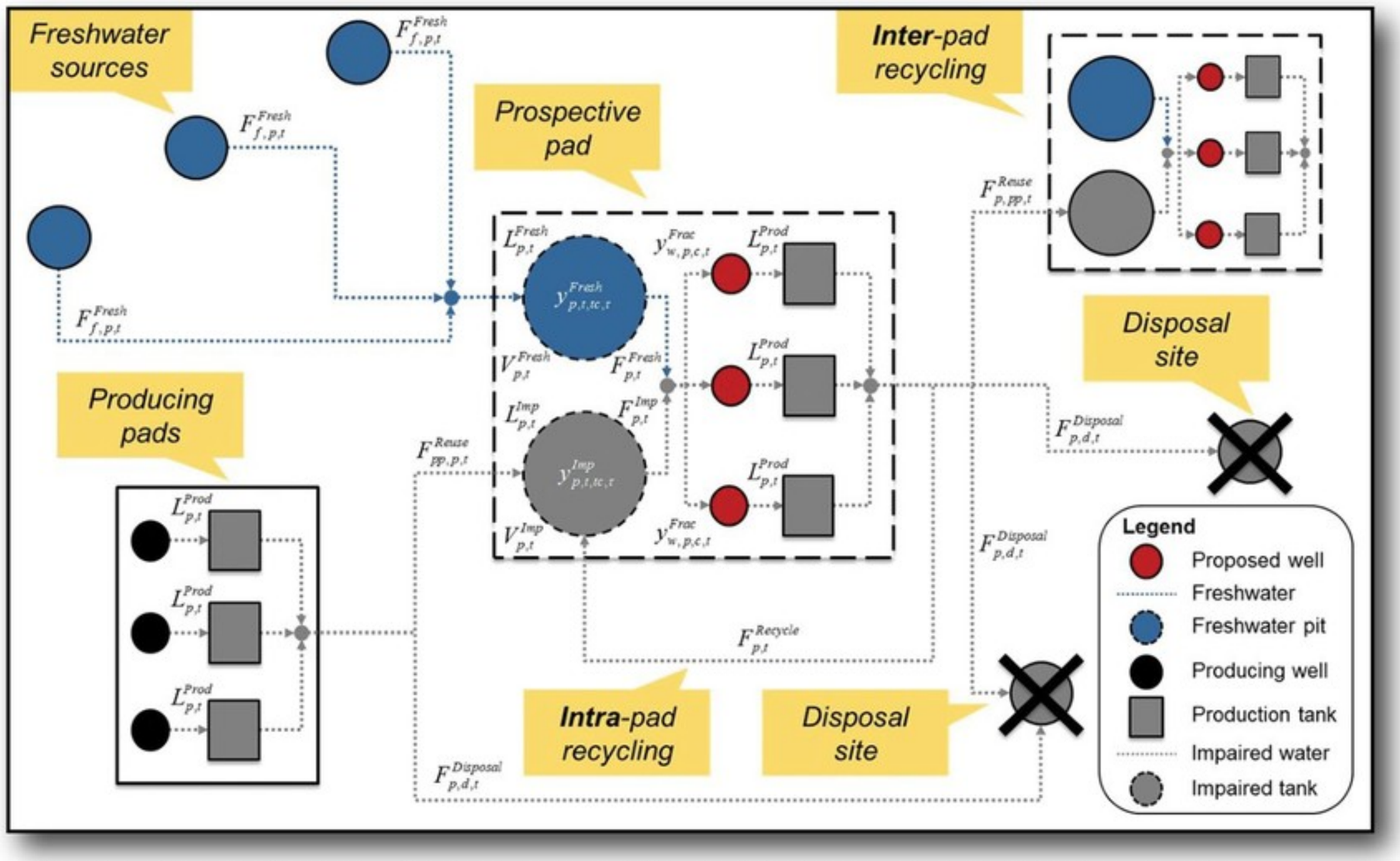

Figure 1: Water management is one of the most cost-intensive aspects of shale gas development.

Courtesy of EQT

Reducing Water Management Costs through Rigorous Optimization

Natural gas production from shale formations is enabled by a combination of three operations: vertical drilling, horizontal drilling and hydraulic fracturing. Hydraulic fracturing refers to the injection of water into a geologically tight formation under high pressure. This well stimulation requires large amounts of water, at times more than a million barrels of water per well. However, a significant portion of the water is eventually recovered again at the surface of the well once it is actively producing natural gas. This "produced" water can be recycled and reused for well stimulation at nearby locations. For this reason, water management is one of the most important and cost-intensive aspects of shale gas development.

At EQT, the water management challenge is addressed by a dedicated Water Operations group. This group is responsible for satisfying the demand for water at EQT's active well development sites, and it has to make a number of important decisions, including: a) whether to use freshwater, production water or both to meet the water demand, b) which sources or well-sites to obtain the water from, and c) how to deliver the respective water volumes (either by trucking or through the use of water pipelines).

Generally, EQT aims to minimize the use of water hauling trucks because they can lead to increased local traffic, road deterioration and the potential for accidents. However, water pipelines are not always available to transport sufficient water volumes to active fracturing sites. In these situations, it is up to the Water Operations group to effectively coordinate water deliveries such that truck traffic is minimized as much as possible.

Historically, experienced water schedulers at EQT manually coordinated water deliveries across the operating region. As EQT grew over the years, this task became increasingly complex and challenging to manage. Therefore, the Optimization Engineering team volunteered to develop a rigorous optimization model that could help the Water Operations group identify safe and cost-effective water delivery schedules.

The model that was developed produces a detailed, day-by-day water delivery schedule for a full week ahead that satisfies the water demand across the entire operating region. The proposed schedule specifies precisely on which date how much water of a certain quality should be moved from a "source" location to a particular "demand" location. The objective function is designed such that both water management costs and the use of water hauling trucks are rigorously minimized. The benefits of water scheduling optimization have been plentiful: comprehensive lookbacks and pilot tests revealed that schedules proposed by the model can save the company several hundred thousand dollars a week. More importantly though, the optimized schedules require less water hauling trucks, thereby minimizing the risks of potential accidents. Efforts are currently under way to commercialize the proposed model so it can be used on a regular basis for active decision support.

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Future Directions

EQT is in the process of establishing a number of real-time operating centers (RTOCs) across the organization. These RTOCs are intended to monitor and control drilling, completions, water management and gas production activities in real time. The establishment of RTOCs may expose many additional opportunities for rigorous optimization at EQT. For instance, the Optimization Engineering team recently came across an intriguing opportunity to improve the efficiency of completions operations by reducing costly downtime. In collaboration with the Completions Engineering team a rigorous, optimization-based analysis confirmed that by parallelizing selected wireline operations (used primarily for reservoir perforation), completions costs could be reduced by several hundred thousand dollars per well. The newly developed model can now be used to support Completions Engineers in real time to decide when to parallelize completions activities.

The Optimization Engineering team is also actively working on developing a rigorous sand delivery scheduling model. Sand is typically used to ensure that fractures induced in the shale formation remain open after the well stimulation. Since individual wells require more than 6,000 tons of sand to be completed, the respective delivery task is a highly complex and cost-intensive aspect of shale gas development. The proposed model is expected to be integrated into a corresponding RTOC and support sand schedulers on a daily basis.

In short, EQT continues to recognize countless opportunities for rigorous optimization that will ultimately ensure safe and cost-effective natural gas production from shale formations in the Appalachian Basin. ORMS

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