REAL-TIME OPTIMIZATION OF A COMPLEX INDUSTRIAL GAS NETWORK

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GAS PIPELINE NETWORKS

Pre-existing network of gas pipelines connecting air separation units and consumers
SCOPE OF CURRENT WORK

• Consider operation of a network of 4 plants, 3 pipelines, and external sources

• Optimize operations under changing demands and fluctuating electricity prices

• Ensure small solution times for application as a real time optimizing tool
  – Select and tune solvers
  – Reformulate the model to be friendlier to solvers
  – Simplify the model if necessary to account for important interactions while maintaining reasonable complexity
## RESULTS WITH DIFFERENT SOLVERS

<table>
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<tr>
<th>SOLVER</th>
<th>LOWER BOUND</th>
<th>UPPER BOUND</th>
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MOTIVATION

• Numerical characteristics of the model proving a challenge to all solvers

• Difficult to use the results from a numerically unstable model in the RTO application

• It is necessary to develop global optimization facilities to deal with problems with many local solutions
ASSUMPTIONS OF THE MODEL

• Consider operation for a single time period
  – Implemented on a real time basis

• All demands are necessarily satisfied

• Demands and electricity prices revealed at start of the period

• No plant dynamics are considered, and pipeline dynamics will be added later

Previous experience at Air Liquide shows presence of multiple local minima. Global optimization techniques essential
NETWORK MODEL: NONCONVEX

- Model for a single column with 40 trays had size 320 differential equations, 1200 algebraic equations (Huang et al., 2013)

- Regression-based models developed at Air Liquide

- Nonconvex models necessary to capture system dynamics
NETWORK MODEL: COMBINATORIAL

• Logic conditions
  – Conjunctions: Certain equipment must be used in concert
  – Disjunctions: Certain equipment cannot be used together
  – Reformulations with binary variables lead to challenging combinatorial characteristics in the model

• Problem Size
  – ~150 binaries, ~600 continuous variables, ~800 equations
CONCLUSIONS

• Novelty of the work
  – Systematic treatment of infeasibilities narrows attention to a source of inconsistency in an infeasible model
  – Model reduction and dynamic scaling strategy to deal with numerical issues

• Impact for industrial applications
  – Systematic treatment of numerically challenging formulations that are ubiquitous in regression models for industrial applications