Long-term Turnaround Planning for Integrated Chemical Sites

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Motivation

• Large companies spend on the order of hundreds of millions of dollars on turnarounds annually

• Coordinating maintenance in integrated sites is a potential for significant savings while providing a long-term turnaround plan

• Practical limitations on manpower
  – Maintenance personnel typically contract workers
  – Infrequent spikes in manpower utilization

• Most scheduling is done using scenario-based analyses
Problem Statement

• Exploit network interactions, storage availability, and prices to schedule maintenance over a multi-year horizon

• Scope:
  – Max. profit
  – Continuous processes
  – Time horizon: 5-15 years
  – Site-wide (each unit is an entire plant)
Mixed Integer Linear Programming Model

• **Objective:** Max. profit
  Revenue – maintenance costs – cost of raw materials

• **Constraints**
  – Network flow constraints
    • Inventory and mass balance
    • Nonnegativity constraints
    • Upper and lower bounds on inventory levels
    • Ratio constraints
MILP model (continued)

- **Constraints**
  - **Big-M constraints on flow between units**
    - Ensure that flow is zero when unit is down; natural upper bound derived from pipe capacities
  - **Financial constraints**
    - Profit in each period is some fraction of average quarterly profit
  - **Manpower constraints**
    - Cumulative manpower needed in each time period is bounded (safety reasons, availability, negotiation)
  - **Turnaround constraints**
    - Required frequencies and durations of turnarounds respected
Details of formulation

• Model statistics:
  – 17-plant integrated site
  – Horizon: 15 years
  – Discretization level: 1 week (~800 time periods)
  – Size of model: 16,000 binaries; 600,000 total
  – Solver used: CPLEX

• Advantages of rolling horizon formulation
  – Transitioning into new schedules
  – More flexibility in scheduling turnarounds
  – Incorporation of seasonal constraints
Modeling improvements

- Transition from cyclic schedule → rolling horizon

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Avg. profit units</th>
<th>Relative gap</th>
<th>Time to solve (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclic</td>
<td>2,564,801</td>
<td>0.7%</td>
<td>36</td>
</tr>
<tr>
<td>Rolling horizon</td>
<td>2,599,788</td>
<td>0.4%</td>
<td>1219 (4 iterations)</td>
</tr>
</tbody>
</table>

Percentage improvement = 1.36%

- Updating big-M constraints

<table>
<thead>
<tr>
<th>Original network</th>
<th>354</th>
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</thead>
<tbody>
<tr>
<td>Modifications</td>
<td>Solve time(s) % improvement</td>
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<tr>
<td>$x_3^U, S_4^0$, $x_7^U$</td>
<td>315</td>
</tr>
<tr>
<td>$x_{S_1,5}$, $x_9^U$</td>
<td>235</td>
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<tr>
<td>$x_{11,5}$, $S_5$</td>
<td>194</td>
</tr>
</tbody>
</table>
Novelty

- Incorporation of three major concerns:
  - Avoidance of maintenance tasks in unfavorable conditions
  - Bringing down peak manpower requirements
  - Balancing quarterly financial performance
Potential Impact

• Successfully demonstrated
  – Turnaround optimization for an industrial-size network
  – Efficient solution while retaining key model features
  – Incorporation of practical considerations

• Next steps: Use of discrete-event simulation to
  – Perform sensitivity analysis to identify most uncertain parameters
  – Debottlenecking network
  – Comparing various recommended schedules