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
  – Disruptions to site network
  – Takes 1—8 week(s)
  – Up to $30,000/hr losses

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

• Practical limitations on manpower – worker contracts, infrequent spikes in manpower utilization, incentive to decrease peak manpower

• Most scheduling is done using scenario-based analyses currently

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)

Schedule refinement and handling uncertainties: Medium-term
Mixed Integer Linear Programming model

- Max. profit = revenue – maintenance – holding – demand satisfaction penalty – raw material and import
- Constraints: network flow, inventory, demand, manpower, financial, turnaround frequencies
- Cyclic vs Rolling horizon schedule

- Model statistics:
  - 17-plant integrated site
  - 15-year horizon
  - 1 week discretization (~800 time periods)
  - 16,000 binaries; 600,000 total
  - CPLEX solver used
Novelty in schedules

Incorporation of three major concerns:

- Avoidance of maintenance tasks in unfavorable conditions
- Bringing down peak manpower requirements
- Balancing quarterly financial performance

<table>
<thead>
<tr>
<th></th>
<th>Avg. Profit</th>
<th>Gap</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclic</td>
<td>2,564,801</td>
<td>0.7%</td>
<td>36</td>
</tr>
<tr>
<td>Roll. H.</td>
<td>2,599,798</td>
<td>0.4%</td>
<td>1219/4</td>
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</table>

1.36% improvement in rolling horizon scheme
Current work

Risk Analysis

• Quantification of risk of plant breakdown and its impact on profits

• TA flexibility post risk-assessment
  – Unfavorable market conditions
  – External factors forcing deferral

• Improving current TA frequencies estimation model
  – Incorporating reliability studies and risk analysis

Global TA Planning

Location 1

Location 2

Location 3

Market A

Market B
Medium-term planning with uncertainty

• Nine months horizon considered **(medium-term)**
• Several months needed to build up downstream inventory **(first six months)**
• Duration of turnaround is uncertain (**why?**)
  – Transport delay: required material/facility delays
  – Discovery work: unexpected damage found during the inspection

### Extended duration

**Flow rate (Inventory level)**

**Schedule (Manpower)**

Robust optimization
Stochastic programming

**Robust Optimization (MILP)**

- **[Min. makespan]** Schedule robust to uncertainty in duration w.r.t. manpower

**Combined Robust and 2-stage Stochastic Programming (MILP)**

- **[Max. profit]** Robust schedule and optimal inventory and production

**Sequential**

**Simultaneous**

**Multi-stage stochastic programming (LP)**

- **[Max. profit]** Determine optimal production and inventory decisions
Best sequential vs. simultaneous approach

Best objective from sequential approach (RO + multi-stage LP)

Week
25 26 27 28 29 30 31 32 33 34 35 36 37 38
Unit
4 5 9 10 11 13
Manpower
1000 800 600 400 200 0
Manpower: Type 1 Type 2 Type 3 Duration: Nominal Extended Objective value: 331149.3

Objective from simultaneous approach (2-stage MILP + multi-stage LP)

Week
25 26 27 28 29 30 31 32 33 34 35 36 37 38
Unit
4 5 9 10 11 13
Manpower
1000 800 600 400 200 0
Manpower: Type 1 Type 2 Type 3 Duration: Nominal Extended Objective value: 338282.4

2% difference, not counting manpower (min. makespan not necessarily best)
## Solution times

**Solved using CPLEX 12.6**

<table>
<thead>
<tr>
<th></th>
<th>RO MILP</th>
<th>Multi-stage LP (implicit form)</th>
<th>RO+2-stage MILP</th>
<th>Multi-stage LP (explicit form; 4 stages)</th>
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<tbody>
<tr>
<td><strong>Avg. Time (s)</strong></td>
<td>&lt; 0.1</td>
<td>19.4</td>
<td>2,714</td>
<td>33.32</td>
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<tr>
<td><strong>Size</strong></td>
<td></td>
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<td>Continuous vars</td>
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<td>42,736</td>
<td>65,032</td>
<td>712,485</td>
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<tr>
<td>Binary vars</td>
<td>252</td>
<td>-</td>
<td>277</td>
<td>-</td>
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</table>

Very inexpensive; but many solutions, and quality of final solution not guaranteed

More expensive; better solutions
Conclusions

• Successfully demonstrated cost savings from a coordinated turnaround of integrated chemical sites
• Efficient solution from a long-term planning perspective while retaining key model features and incorporating practical considerations
• Accounted for uncertainties in TA duration and any discovery work through medium-term planning schemes
• Combined robust optimization with stochastic programming