Ice cream scheduling

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Problem overview

Stage 1
- Mixing of products
- Pasteurization

Intermediate Stage
- Intermediate Storage
- Ageing

Stage 2
- Freezing
- Packing

All products

MIX

ST

ST

ST

ST

Pack

Product type 1

Product type 2
Process Specifics

- **Production runs**
  - Single continuous packing campaigns
  - Mixer changes between products
  - Only mixing full storage tanks
  - Batch identity must be retained

- **Sequence dependent changeovers**

- **Additional periodical cleaning periods**
Main Challenge

- Intermediate inventory
  1. Limited storage capacity leads to many mixer switches
     - Must ensure continuous packing runs
  2. Considerably more storage tanks than mixers and packers
     - Model size largely determined by storage stage
Dedicated time slots

1. Limited storage capacity leads to many mixer switches

- Observation: Almost never two consecutive mixing runs of the same product class (same packer)
- Dedicate product types to periods \( \rightarrow \) Smaller model

- Empty periods ensure flexibility
2. Considerably more storage tanks than mixers and packers
   - Model size determined by intermediate storage stage
   - Alternative inventory modeling
     - Aggregated storage
     - Relate mixing and packing periods
Aggregated Storage Model
Aggregated Storage Model

- **Advantage**
  - Smaller model
    - Only one inventory per product type to consider
    - Less breaking up of periods
Aggregated inventory storage

- **Challenges**
  - No mixing of different products
  - Batch identity

- Checking inventory at end period is not enough
  - Sufficient storage must be available at start
  - Only production of full tanks
  - Mixing products never required if storage available
Related Period Model

\[ T_{m1} + T_{m2} + T_{m1} + T_{m2} \leq T_P \]

**MIXER**

\[ T_{m1} + T_{m2} + T_{m1} + T_{m2} \leq T_P \]

**PACKER**

\[ T_{m1} + T_{m2} + T_{m1} + T_{m2} \leq T_P \]

**PACKER**

\[ T_{m1} + T_{m2} + T_{m1} + T_{m2} \leq T_P \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

**Packer1**

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

\[ T_{P} \]

**Number of storage tanks**
Related Periods Model

- No intermediate stage to model, simpler model
- Empty periods not counted when relating periods

![Diagram of Related Periods Model](image)
Small Example Problem

- 48 hr horizon
- 2 hr cleaning period

One Mixer
Six Products

Four 4000kg Tanks, Products 4-6

Two 8000kg Tanks, Products 1-3

First Packer
Products 1-3

Second Packer
Products 4-6

MIX

ST

ST

ST

ST

ST

PACK

PACK
## Computational Results

### Feasibility

<table>
<thead>
<tr>
<th>Model</th>
<th>Time slots</th>
<th>Variables (Integer)</th>
<th>Constraints</th>
<th>Required Comp. Time*</th>
<th>Number of Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregated Storage Model</td>
<td>19</td>
<td>1559(302)</td>
<td>2214</td>
<td>&gt;1 hr</td>
<td>&gt;30k</td>
</tr>
<tr>
<td>Aggregated Storage Model - Dedicated Time Periods</td>
<td>19</td>
<td>1559(302)</td>
<td>2216</td>
<td>320s</td>
<td>2701</td>
</tr>
<tr>
<td>Related Periods Model</td>
<td>36</td>
<td>1946(108)</td>
<td>2088</td>
<td>6.97s</td>
<td>62</td>
</tr>
</tbody>
</table>

### Makespan minimization

<table>
<thead>
<tr>
<th>Model</th>
<th>Time slots</th>
<th>Variables (Integer)</th>
<th>Constraints</th>
<th>Required Comp. Time*</th>
<th>Number of Nodes</th>
<th>Makespan</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM - DTP</td>
<td>19</td>
<td>1559(302)</td>
<td>2216</td>
<td>411 min</td>
<td>916034</td>
<td>45.61hr</td>
</tr>
<tr>
<td>RPM</td>
<td>36</td>
<td>1946(108)</td>
<td>2088</td>
<td>20 min</td>
<td>59096</td>
<td>45.61hr</td>
</tr>
</tbody>
</table>

* Gurobi 3.0 was used as solver
Results: Schedules

Feasibility, Aggregated Storage Model

Makespan minimization, Aggregated Storage Model

Makespan minimization, Related Period Model
Future Work

- Compare with RTN formulation

- Larger case
  - 120 hr horizon, 8 products
  - Application of heuristics

- Planning model