Press Sheet Optimization for Open Loop Control of Industrial Scale Gang-Run Printing

Daniel Fullmer
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IDEA Labs
Information & Decision Algorithms Laboratories
Printed Products
Press Sheets
Press Sheet Templates

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3/19/2013
Press Sheet Templates
Problem Description

- Minimize the total cost of production
- Choose press sheets from press sheet templates
- Choose which orders to print on each press sheet
- Choose presses to print each press sheet
- This decision is made daily.
- Products that are due today must be printed.
- Products not due today may optionally be printed.
Costs

- Paper Cost
- Plate Cost
- Ink Cost
- Press Time / Press Labor Cost
- UV Spot and Full Cost / UV Labor Cost
- Cutting Time / Cutting Labor Cost

- Cost tradeoffs due to press sheet type, press, quantity, labor, etc.
Digital Printing
Offset Printing
Offset Printing

The Offset Process

- Tray with ink
- Ink is distributed evenly
- Applied to the plate
- Offset to blanket
- Applied to the paper

Diagram:
- Ink rollers
- Water rollers
- Plate cylinder
- Offset cylinder
- Impression cylinder
- Paper
- Water
UV Coating
Cutting
Cutting Time
Order Placement Complexity

• Orders can be placed multiple times on each press sheet.
• Orders can be split across multiple press sheets
• Orders can be “over-printed”
• 1-sided orders may be placed on 2-sided press sheets
• “UV Full” coated orders may be placed on “UV Spot” press sheets
Problem Formulation

\[
\begin{align*}
\min_{b_d, b_d', b_d''} & \sum_{p \in P} \sum_{a \in A} \sum_{m \in M_p} \sum_{q \in Q} c_{p,a,m,q} b_{p,a,m,q} \\
& + \sum_{t \in T} \sum_{a \in A} \sum_{q \in Q} k_{l,a,q} (v_{l,a,q} + w_{l,a,q} - r_{l,a,q}) \\
\text{s.t.} & \quad v_{l,a,q} \leq r_{l,a,q} \leq v_{l,a,q} + w_{l,a,q} \quad (1a) \\
& \quad r_{l,a,q} = \sum_{q_{to} \in Q} d_{l,a,q_{to}} \quad (1b) \\
& \quad r'_{l,a,q} = \sum_{q_{from} \in Q} d_{l,a,q_{from}} q_{from} \quad (1c) \\
& \quad r''_{l,a,q} = r'_{l,a,q} - \sum_{q_{to} \in Q} d_{l,a,q_{to}} q_{to} \quad (1d) \\
& \quad + \sum_{q_{from} \in Q} \sum_{q \in Q} \left( d_{l,a,q_{from}} + d_{l,a,q_{from}} - q_{from} \right) \quad (1e) \\
& \quad r'''_{l,a,q} = \sum_{a \in A_{to}} d'_{l,a_{to}} \quad (1f) \\
& \quad r''''_{l,a,q} = \sum_{a_{from} \in A} d''_{l,a_{from}} \quad (1g) \\
& \quad r'''_{l,a,q} \leq \sum_{p \in P} \sum_{m \in M_p} a_{p,a,m,q} \quad (1h)
\end{align*}
\]

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>(b_{p,a,m,q} \in \mathbb{N})</td>
<td>Number of press sheet template (p) to produce with attributes (a) on machine (m) at quantity (q)</td>
</tr>
<tr>
<td>(r_{l,a,q} \in \mathbb{N})</td>
<td>Number of orders of product type (t) and attributes (a) at quantity (q) to print</td>
</tr>
<tr>
<td>(r'_{l,a,q} \in \mathbb{N})</td>
<td>Number of orders of product type (t) and attributes (a) at quantity (q) to print (after overprinting)</td>
</tr>
<tr>
<td>(r''_{l,a,q} \in \mathbb{N})</td>
<td>Number of orders of product type (t) and attributes (a) at quantity (q) to print (after splitting)</td>
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<tr>
<td>(r'''_{l,a,q} \in \mathbb{N})</td>
<td>Number of slots of product type (t) and attributes (a) at quantity (q) to print (after attributes)</td>
</tr>
<tr>
<td>(d_{l,a,q_{from}} \in \mathbb{N})</td>
<td>Number of times to treat orders of product type (t), attributes (a), and quantity (q_{from}) as an order with quantity (q_{to})</td>
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<tr>
<td>(d'<em>{l,a</em>{to}} \in \mathbb{N})</td>
<td>Number of times to treat orders of product type (t), attributes (a), and quantity (q_{from}) as an order with quantity (q_{to})</td>
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**TABLE II**

**INTEGER DECISION VARIABLES**
Mixed Integer Linear Programming

\[
\begin{align*}
\text{maximize} & \quad c^T x \\
\text{subject to} & \quad Ax \leq b \\
\text{and} & \quad x \geq 0
\end{align*}
\]

Branch and Cut
- Branching
- Cutting Planes
- Heuristics (Randomized Rounding, Neighborhood Search, etc.)

Integer Program: Branch and Bound (or Divide and Conquer)
Methods

- Used Gurobi Integer Linear Programming Solver
- Real data from a factory
- Compare with manual gang-run printing
Results

- Optimality Gap: 0-2%
- Total Cost Difference: 14%
Conclusions

• This formulation can reduce the cost of production significantly.
• Even though this problem is NP-complete, Integer Linear Programming solvers can produce good solutions quickly.

Future work:
• Use predictions of future orders to make better decisions.
• Consider the risk of failed production.