Kimberly-Clark Latin America builds an Optimal Scheduling System

Daniel H. Wagner Award Presentation

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Jorge Arias
Esteban Rodríguez
David Sánchez
Germán Riaño, PhD.
Agenda

♦ Introduction
♦ Optimization Model
♦ SPN – Decision Support System
♦ Results and Impact
♦ Conclusions
Introduction

Background
OR in KC LAO
KC PSU Partnership
Kimberly Clark Corporation

- Headquarters in Dallas, TX
- 56,000 employees
- Operations in 35 countries, brands sold in 150.
- 19.1 billion in sales
- 2.8 billion in operating profit
Latin American Operations (LAO)

- Andean: 43%
- Brazil: 25%
- CA&C: 20%
- Austral: 12%

Latin American GDP
Billion of current US dollar 2000

- 2000: 2000
- 2001: 2050
- 2002: 2500
- 2003: 3000
- 2004: 3500
- 2005: 4000
- 2006: 4500
- 2007: 5000
- 2008: 5500
Operations Research & Analytics Group

- Organizational Growth
  - Internships
  - Talent Pipeline

- Technical Business Support
  - DC Layout (Re) Design
  - Market Mix Opt

- Operational Excellence
  - Dist./Mfg Footprint
  - Inventory Policy
  - Throughput Optimization

- Innovation
  - University Collaborative Projects Research
KCC – PSU Partnership

- Leverage OR to forge a strategic competitive advantage
- 2 KCC employees have completed IE graduate degrees at PSU
- Multiple OR projects in different areas
- 3 PSU PhD and 3 MSIE graduates recently joined KCC
- 1 KCC employee now a PSU faculty
- 10 PSU interns have worked for KCC
Project Team

- Esteban Rodriguez
  - OR&A IT Leader

- German Riaño, PhD
  - LAO OR Manager
  - OR Senior Analyst

- Danilo Abril
  - OR Senior Analyst

- Guerrero Pinochet
  - LAO OR&A Director

- Jorge Arias
  - OR Junior Analyst

- Vittal Prabhu, PhD
  - Professor
  - Penn State

- Nazrul Shaik, PhD
  - Assistant Prof.
  - U. Of Miami

- David Sanchez
  - OR Junior Analyst
Executive Endorsement
Optimization Model

Problem Complexity
Literature Review
Model Overview
Heuristics
Problem Complexity

- Sequence-dependent Setups
- Number of SKUs
- Machine capabilities
- Several markets
- Non Stationary Demand

Problem Complexity
Literature Review

SOLUTION TECHNIQUE
Lagrangian Relaxation
- Afentakis and Gavish (1986)
- Draby et al. (1992)

Greedy Approaches
- Dixon and Silver (1982)

Meta-heuristics
- Simpson and Erengue (1998)
- Moon (2004)

Column Generation
- Vanderbeck (1998)

PROBLEM MODELING
Classical ELSP
- Elmaghraby (1978)
- Jans and Degraeve (2007, 2008)

Multi-Machine extension
- Carreno (1990)
- Bollapraganda (1999)
- Pesenti (2003)

INDUSTRIAL APPLICATIONS
- Savelsbergh and Nemhauser (1993)
- Cordier et al. (1999)
- Denton (2006)
- Wolsey (2002)
Model Overview

- DC Target Inventories $I_{it}$
- Setup Costs & Times $t_{ij}, s_{ij}$
- Holding & BO Costs $h_{it}, b_{ikt}$
- Weekly Forecast $D_{ikt}$
- DC Current Inventory $I_{i0}$
- Machine Capabilities $p_m$

- Production lot sizes ($x_{imt}$)
- Weekly production sequence ($\delta_{mu}^j, \gamma_{mu}^j$)
- Expected Inventory ($I_{it}$)
Model Equations

♦ **Inventory Balance**

\[ I_{it} = I_{i,t-1} + \sum_{m \in M_i} x_{imt} - \sum_{k \in K} v_{ikt} \]

- **End of week Inventory**
- **Previous week Inventory**
- **Production**
- **Sales Volume**
Model Equations

♦ Inventory Balance

\[ I_{it} = I_{i,t-1} + \sum_{m \in M_i} x_{imt} - \sum_{k \in K} v_{ikt} \]

♦ Demand Usage

\[ D_{ikt} = v_{ikt} + B_{ikt} - B_{ik,t-1} \]
Model Equations

♦ **Inventory Balance**

\[ I_{it} = I_{i,t-1} + \sum_{m \in M_i} x_{imt} - \sum_{k \in K} v_{ikt} \]

♦ **Demand Usage**

\[ D_{ikt} = v_{ikt} + B_{ikt} - B_{ik,t-1} \]

♦ **Target Inventory**

\[ I_{it} - \sum_{k \in K} B_{ikt} = I̅_{it} + \tilde{I}^+_it - \tilde{I}^-it \]

- Net inventory
- Target
- Overage and underage
Activity Representation

Balance Equations

\[ \gamma_{it} = \sum_{l \in B_{lm}} \gamma_{l, t-1}^{li} + \sum_{l \in A_{lm}} \delta_{mt}^{li} = \sum_{j \in B_{lm}^+} \gamma_{mt}^{lj} + \sum_{j \in A_{lm}^+} \delta_{mt}^{lj}. \]
Model Equations

◊ Capacity Constraint

\[ W_{mt} = \sum_{(i,j) \in \mathcal{A}_m} t_{ijm}(\delta_{mt}^{ij} + \gamma_{mt}^{ij}) + \sum_{i \in \mathcal{P}_m} \frac{x_{imt}}{\mu_{im}} \leq K_{mt} \]

- Used Time
- Setups Time
- Production Time
- Available Hours
Model Equations

- **Capacity Constraint**
  \[
  W_{mt} = \sum_{(i,j) \in A_m} t_{ijm}(\delta_{mt} + \gamma_{mt}) + \sum_{i \in P_m} \frac{x_{imt}}{\mu_{im}} \leq K_{mt}
  \]

- **Minimum Batch**
  \[
  x_{imt} \geq L_i \left( y_{imt} - \gamma_{m,t-1}^{ii} - \gamma_{mt}^{ii} \right)
  \]
  Production Batch  Minimum Batch  Is produced only this week?
Model Equations

♦ Capacity Constraint

\[ W_{mt} = \sum_{(i,j) \in A_m} t_{ijm}(s_{ij} + \gamma_{ij}) + \sum_{i \in P_m} \frac{x_{imt}}{\mu_{im}} \leq K_{mt} \]

♦ Minimum Batch

- \[ x_{imt} \geq L_i (\gamma_{imt} - \gamma_{m,t-1}^{ii} - \gamma_{m,t}^{ii}) \]
- \[ x_{imt} + x_{im,t-1} \geq L_i (\gamma_{m,t-1}^{ii}) \]

Two-week production batch

Minimum batch

Is produced on both weeks?
Model Equations

♦ Capacity Constraint

\[ W_{mt} = \sum_{(i,j)\in \mathcal{A}_m} t_{ijm}(\delta_{mt}^{ij} + \gamma_{mt}^{ij}) + \sum_{i\in \mathcal{P}_m} \frac{x_{imt}}{\mu_{im}} \leq K_{mt} \]

♦ Minimum Batch

- \[ x_{imt} \geq L_i (\gamma_{imt} - \gamma_{m,t-1}^{ii} - \gamma_{mt}^{ii}) \]
- \[ x_{imt} + x_{im,t-1} \geq L_i (\gamma_{m,t-1}^{ii}) \]

♦ Prevent Subtours

\[ r_{jmt} \geq r_{imt} + 1 - N_m \left( 1 - \delta_{mt}^{ij} \right) \]

If \( \delta_{mt}^{ij} = 1 \), then \( r_{jmt} \geq r_{imt} + 1 \)
Objective Function

- **Income**
  \[
  \text{Max} \sum_{t \in T} \sum_{i \in I} \sum_{k \in K} \rho_{ikt} v_{ikt}
  \]

- **Setup Costs**
  \[
  - \sum_{t \in T} \sum_{m \in M} \sum_{(i,j) \in A_m} s_{ijt} (\delta_{mt}^{ij} + \gamma_{mt}^{ij})
  \]

- **Holding, Shortage and Backorder Cost**
  \[
  - \sum_{t \in T} \sum_{i \in I} \left( h_{it} l_{it} + \bar{b}_l \bar{l}_{it} + \sum_{k \in M} b_{ik} B_{ikt} \right)
  \]

- **Production Costs**
  \[
  - \sum_{t \in T} \sum_{i \in I} \sum_{m \in M} \left( c_{imt} x_{imt} + \alpha_{mt} W_{mt} \right)
  \]
Why Heuristics?

<table>
<thead>
<tr>
<th></th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Machines</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Number of SKUs</strong></td>
<td>80</td>
</tr>
<tr>
<td><strong>Binary (K)</strong></td>
<td>18</td>
</tr>
<tr>
<td><strong>Constraints (K)</strong></td>
<td>25</td>
</tr>
<tr>
<td><strong>Execution Time (min)</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>Attained GAP (%)</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Variables (K)</strong></td>
<td>28</td>
</tr>
</tbody>
</table>

Note:
- Processor: Intel Core 2 Duo T5600 1.83 GHz
- Memory (RAM): 2.00 GB
Assignment Model

SKUs

1
2
3
4
5

Demand

$D_{ikt}$

Costs

$c_{imt}$

Machines

1
2
3

Capacities

$\sum_{i \in P_m} x_{imt} \leq K_{mt}$

Redefine Capabilities

$P_m$

Solve LP

$x_{imt}$
Arc Generation Strategy

Add all arcs

Solve TSP

Define cyclic distance

\[ d_{61}^m = 2 \]

\[ d_{12}^m = 3 \]

Keep only Arcs that satisfy

\[ \mathcal{A}_m = \{(i, j) : i, j \in P_m, d_{ij}^m \leq D_m \} \]
Arc Generation Strategy Impact

… using only 82% of the computing time!.

… we get 99.5% of the profit…

With 50% of the arcs…
Solve model for \( \{n_1\} \).

Fix sequence for \( n_1 \) in the graph.

...and solve for \( \{n_1, m_2\} \).

Fix sequence for \( \{n_1, m_2\} \).

...and solve for \( \{n_1, m_2, m_3\} \).

Fix sequence for \( \{n_1, m_2, m_3\} \).

...and solve for \( \{n_1, m_2, m_3, m_4\} \).

Final step: Consider small machine and solve for its sequence using warm-start.
Successive Machine Inclusion Algorithm Impact

Solution Time

- 100%
- 16%

Objective Function

- 100%
- 99.8%

- Sequential Strategy
- Base Model
Decision Support System
Supply Planning Network
Graphical User Interface snapshots
SPN Framework

User Interface

Web Application
Microsoft Office® Reports
User's Community Site

Web Services
Optimization Engine
Math & Stats Engine
Smart Agents Console
Simulation Engine

Databases
Corporate ERP
Microsoft SQL Server®

Business Rules
Multiple scenarios: Just one click for optimization
Detailed Production Plan
Business Results: Graphical analytic tools for planners
Results & Impact

Roll Out
Performance Indicators
Traditional vs. Optimal Plan Comparisons
Roll-Out

Countries: 10
Mills: 21

Stage 1 (2007-2009)
- Initial prototype in 1 country

Stage 2 (2010)
- Extension to 4 additional countries in similar mills

Stage 3 (2011-2012)
- Whole region implemented.
How come this does not change?

Germán Riaño, Ph.D., 10/20/2010
Results

♦ Improved Performance Indicators: Inventory, service levels and production (yield, uptime).

♦ Traditional vs. Optimal Plan: Higher profits predicted when comparing to traditional plan.
Planner’s Testimony
Performance Indicators

We achieved a 9% increase even with the number of SKUs growing!

Initial Uptime: 76%

Final Uptime: 85%
Model setup costs were 34% higher

Model holding costs were 23% lower

Overall, costs were reduced by 12%
# Manual vs. Plan Comparison

## Mill 1 – Instance A

<table>
<thead>
<tr>
<th>Metric</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Rate (%)</td>
<td>+9.9%</td>
</tr>
<tr>
<td>Income (USD)</td>
<td>+6.2%</td>
</tr>
<tr>
<td>Production cost (USD)</td>
<td>-6.0%</td>
</tr>
<tr>
<td>Profit (USD)</td>
<td>+6.0%</td>
</tr>
</tbody>
</table>

Some times the Fill Rate is improved,…

## Mill 2 – Instance B

<table>
<thead>
<tr>
<th>Metric</th>
<th>Variation</th>
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</thead>
<tbody>
<tr>
<td>Setup Cost (USD)</td>
<td>-17.4%</td>
</tr>
<tr>
<td>Holding Cost (USD)</td>
<td>+8.5%</td>
</tr>
<tr>
<td>Setup + Holding Cost (USD)</td>
<td>-13.6%</td>
</tr>
<tr>
<td>Fill Rate (%)</td>
<td>0%</td>
</tr>
<tr>
<td>Machine Utilization (%)</td>
<td>-1%</td>
</tr>
</tbody>
</table>

Some times Setup + Inventory Cost are reduced,

… but the model balances it all!
Conclusions
Conclusions

♦ Development of a model to manage production planning and scheduling with a scientific basis for a challenging environment

♦ This project became beachhead in the introduction of OR in KC LAO.

♦ Creation of ingenious heuristics that have sped up solution time

♦ The approach used to solve the model can be applied to many other industries that face sequence-dependent setups
Thank you!
Planning Process

S&OP Demand Planning

- Machine Capacity
- Storage Capacity
- Production Costs
- Transportation Costs
- On-hand Inventories
- In-transit Inventories

Unconstrained Forecast

Ideal Long Term Production Cycles

- Long-term production cycles
- End-of-month target inventories

- Weekly Forecast
- Setup Costs and Times
- Nominal Sequences
- Raw Materials Availability
- Minimum Batch Sizes
- Weekly sales

Master Production Schedule

- Current Daily Orders
- On-hand Inventories
- Transportation Costs
- SKU Segmentation
- Customer Segmentation

Demand Allocation and End-of-Month Inventory Targets

Monthly/Biweekly Production Quantities

Production Planning and Scheduling

Raw Materials Planning

- Raw Materials Purchases and Availability

Distribution Resource Plan

- Short lead-time materials

Delivery plan

Transportation

Resource Plan

Daily Production Sequence and Quantities
Main Trade Offs

We save this holding cost,...

...but incur an additional setup cost

Inventory

Time