Production-Distribution Coordination of Industrial Gases Supply-chains

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Background and Motivation

Industrial Gases Supply-Chain
- Multiple Plants and Depots (located or not at plants)
- Multiple Products (LIN, LOX etc.) and Product Grades
- Over-the-fence, call-in and distributed customers (some shared customers)
- Storage facilities at production sites and customer locations

Goal
To quantify and access the savings associated with the Production-Distribution Coordination at Operational Level using an approximate model

Problem Statement and Main Assumptions

Given
- Plants, Products, Operating Modes and Production Limits
- Daily Electricity Prices (off-peak and peak)
- Customers and their demand/consumption profiles
- Max/Min inventory at production sites and customer locations
- Alternative sources and product availabilities
- Depots, Truck availabilities and capacities, Distances
- Fixed Planning Horizon (usually 1-2 weeks)

Decisions in each time period t
- Modes and production rates at each plant
- Inventory level at customer location and plants
- How much product to be delivered to each customer through which route

Objective Function
- Minimize total production and distribution cost over planning horizon

Main Assumptions – Distribution Side
- Two time periods per day (peak and off-peak) are considered
- Trucks do not visit more than 4 customers in a single delivery
Mathematical Model (MILP)

**Objective**

Minimize total Production and Distribution Cost

**Constraints on Production Side**

- Production Cost = Fixed Start-up cost + Variable production cost
- Min/Max Production Capacity Constraints in each mode of operation
- Logic Constraints for switching between various modes of operation
- Max/Min Inventory limits at the production sites
- Plant Inventory Balance Constraints
- Demand satisfaction for pick-up customers
- Ad Hoc Production Models

**Main binary variables**

- mode selection $B_{pm,t}$

**Constraints on Distribution Side**

- Distribution Cost = Cost of deliveries by trucks + purchases from competitors
- Max/Min Inventory limits at the customer locations
- Customer Inventory Balance Constraints
- Truck Capacity constraints
- Material balance constraints for product pick-up and delivery points
- Max product purchase limit from alternative sources

**Main binary variables**

- truck-customers association $y_{kt}$
- truck-source association $y_{kpt}$

**Route Generation Algorithm** developed to obtain alternative routes for truck distribution.

Supply-chain Example

**Definition of Customer Sets**:

- Depots
- Plants
- Customer sets
- Customers

Meaning of continuous variables to transfer products from plants to customers:

- $D_{truck_{p,t}}$
- $E_{kpt}$
Supply-chain Example

Meaning of continuous variables to transfer products from plants to customers:

Depots → Plants → Customer sets → Customers

Material flow (model’s perspective)

Plant - Truck → Truck - Customer Set → Customer Set - Customer

Industrial Size Test Case

- 4 Plants / Depots
- 2 products (LIN, LOX)
- 2-4 production modes for each plant
- 2 alternative sources
- 14 time periods (peak and off-peak)
- 37 trucks (25 for LIN, 12 for LOX)
- Min/max inventory, distances, electricity prices, truck deliveries, etc.

Models implemented with GAMS
CPU results obtained with solver CPLEX 12.3

Industrial Size Test Case

Results are compared with historical data by fixing volume sourced from each plant.

Comparison of volume sourced: optimal model solution vs historical data.

Optimal solution shifts production and distribution from plant $P_1$ to plant $P_4$, mainly due to lower electricity costs at $P_4$. Good solutions found in few CPU sec.!!!
Industrial Size Test Case – Results

Production cost % for each plant

<table>
<thead>
<tr>
<th>Plant</th>
<th>Historical</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>47%</td>
<td>39%</td>
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<tr>
<td>Plant 2</td>
<td>30%</td>
<td>23%</td>
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<td>Plant 3</td>
<td>16%</td>
<td>17%</td>
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<tr>
<td>Plant 4</td>
<td>13%</td>
<td>23%</td>
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Percentage of Total Historical Cost

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<tr>
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<th>Optimized</th>
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<tr>
<td>58%</td>
<td>31%</td>
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<td>42%</td>
<td>40%</td>
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Total Production Cost
Total Distribution Cost

Savings = \( \frac{\text{Amount saved}}{\text{Historical model total}} \) = 9% per week

Improved Route Generation Algorithm

Main Features:

- Exact distances among plants, depots, & customers obtained by GIS software.
- Route distances calculated using TSP method.
- Multiple parameters for each plant and product.
- Added routes to import product to plants (shutdown scenario)
- Alternative sort criteria to rank potential routes:
  - Distance (miles)
  - Logistics Ratio ($ / volume delivered)

Improved Route Generation Algorithm

Progress Status, Statistics and Detailed Results

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<thead>
<tr>
<th>Plant</th>
<th>Product</th>
<th>Stage</th>
<th>Plant 1</th>
<th>Plant 2</th>
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Conclusions and Future Work

Conclusions

- Proposed Simultaneous Production-Distribution MILP Model for optimal operational planning of industrial gases supply-chain
  - Multiple products, plants and depots
  - Route generation algorithm
  - Ad hoc production models
- Selection of routes is a critical aspect to reduce the total cost of production and distribution.
- Good quality solutions for industrial size examples obtained in short CPU times.
- Significant potential savings due to better coordination of production and distribution.

Future work

- Uncertain behavior analysis (electricity prices & customer demands)
  - Stochastic optimization
  - Robust optimization