Quantitative Methods for Strategic and Investment Planning in the Oil-Refining Industry

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Refining Optimization
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Refining Optimization

PETROBRAS Current Tool for Strategic Planning (PLANINV) – LP
No Production Scenario Synthesis
Only optimize streams transfers (oil and fuels import/export, market supply)

Mixed-Integer (MILP) + Nonlinear (NLP) Models

\[ y_{\text{R},\text{U},\text{N},\text{T}} = \text{expansion of an existent unit} \]
\[ y_{\text{I},\text{R},\text{U},\text{N},\text{T}} = \text{installation of a new unit} \]
\[ y_{\text{F},\text{R},\text{U},\text{N},\text{T}} = \text{operational flow} \]
\[ y_{\text{C},\text{R},\text{U},\text{N},\text{T}} = \text{total capacity} \]
\[ y_{\text{E},\text{R},\text{U},\text{N},\text{T}} = \text{expansion capacity} \]
\[ y_{\text{Q},\text{R},\text{U},\text{N},\text{T}} = \text{installation capacity} \]

\[ \text{in} \times \text{out} = \text{in} \times \text{out} \]

\[ \text{NLP} \quad \text{OPREF} \quad \text{INVREF} \]

\[ \text{Crude Diet} \quad \text{Processing} \quad \text{Blending} \]

<table>
<thead>
<tr>
<th>(u)</th>
<th>Unit Products Properties:</th>
<th>(Q_{S,u} = f(Q_{F,u}, PF_{u,p}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(p)</td>
<td>Splitter:</td>
<td>(Q_{S,u} = \sum Q_{u,a,p})</td>
</tr>
<tr>
<td>(s)</td>
<td>(Q_{S,u} = f(Q_{F,u}, PF_{u,p}, V_{u,v}))</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{INVREF} \]
\[ \text{OPREF} \]
\[ \text{Q}\text{P}\text{SQC} \quad \text{NLP} \]

\[ \text{output} \]
\[ \text{input} \]

\[ \text{Project execution} \]
\[ \text{NPV} = \sum (\text{sales} - \text{crude} - \text{op. costs}) - \sum \text{invest. costs} \]
Capital Cost Constraint

\[ \sum_{R} \sum_{U} \sum_{N} \left( Q_{E_{R,U,N}} + Q_{E_{R,U,N}}^{*} y_{E_{R,U,N}}^{*} \right) + Q_{I_{R,U,N}} + Q_{I_{R,U,N}}^{*} y_{I_{R,U,N}}^{*} \right) \leq C(t) \times t \quad \text{capital for investment p/time} \]

Logic Constraints for Expansions and Installations

\[ \sum_{N} \left( y_{E_{R,U,N}} + y_{I_{R,U,N}} \right) \leq 1 \quad \forall \quad r,u \quad \text{only one expansion or installation p/time} \]

\[ \sum_{N} y_{E_{R,U,N}} \leq 1 \quad \forall \quad r,u \quad \text{expansion can appear only once during all time} \]

\[ \sum_{N} y_{I_{R,U,N}} \leq 1 \quad \forall \quad r,u \quad \text{installation can appear only once during all time} \]

\[ \sum_{N} \left( y_{E_{R,U,N}} + y_{I_{R,U,N}} \right) \leq 1 \quad \forall \quad r,u \quad \text{only one expansion or installation p/group p/time} \]

### Crude Diet and Processing Equations

**Crude diet**

\[ Q_{CDU} = \sum Q_{CRUDE,CDU} \]

\[ PF_{CDU} = f(Q_{CRUDE,CDU}, PF_{CRUDE,CDU}) \]

**Improved Swing-Cut** (Menezes, Kelly & Grossmann, 2013)

\[ Q_{CDU} = \sum Q_{CRUDE,CDU} \]

\[ PF_{CDU} = f(Q_{CRUDE,CDU}, PF_{CRUDE,CDU}) \]

**Other models** (Moro, Zanin & Pinto, 1998)

\[ Q_{P_{FCC}} = Q_{P_{FCC}}^{+} \left( 1 + \frac{P_{F_{CDU}}}{P_{F_{CDU}}} \right) \]

\[ Q_{P_{DASFA}} = Q_{P_{FCC}}^{+} \left( 1 + \frac{P_{F_{PDA}}}{P_{F_{PDA}}} \right) \]

\[ P_{F_{TFA}} = PF_{TFA} \left( 1 - \frac{P_{TFA}}{P_{TFA}} \right) \]

### Blending Equations

<table>
<thead>
<tr>
<th>Property Group</th>
<th>PF or IP base</th>
<th>Property Name</th>
<th>PF or IPF (Property Index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACID</td>
<td>Mass</td>
<td>Acidity</td>
<td>PF_{Vol} = \frac{P F_{Vol}}{\sum_{P} F_{Vol}}</td>
</tr>
<tr>
<td>GRAV</td>
<td>Vol</td>
<td>Gravity</td>
<td>PF_{Mass} = \frac{P \cdot GRAV Vol}{\sum_{P} GRAV Vol}</td>
</tr>
<tr>
<td>SULF</td>
<td>Mass</td>
<td>Sulfur Content</td>
<td></td>
</tr>
<tr>
<td>CCR</td>
<td>Mass</td>
<td>Conradson Carbon Residue</td>
<td></td>
</tr>
<tr>
<td>Volatility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIST</td>
<td>Vol</td>
<td>Distillation</td>
<td>IP_{RVP} = \left( 1.0 P + 32 \right) \frac{7.8}{549} \left( 1000 V - 1409 \right)</td>
</tr>
<tr>
<td>RVP</td>
<td>Vol (IP)</td>
<td>Reid Vapor Pressure</td>
<td></td>
</tr>
<tr>
<td>FLASH</td>
<td>Vol (IP)</td>
<td>Flash Point</td>
<td>IP_{FLASH} = e^{1.949 (IP) - 14.99}</td>
</tr>
<tr>
<td>Volatility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MON</td>
<td>Formula</td>
<td>Motor Octane Number</td>
<td>PF_{MON} = \sum_{I} MON Vol</td>
</tr>
<tr>
<td>RON</td>
<td>Formula</td>
<td>Research Octane Number</td>
<td></td>
</tr>
<tr>
<td>CETAN</td>
<td>Vol</td>
<td>cetane Number</td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUM</td>
<td>Vol</td>
<td>Gum</td>
<td>IP_{GUM} = \frac{P_{GUM}}{\sum_{P} P_{GUM}}</td>
</tr>
<tr>
<td>Fluidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VISC</td>
<td>Vol (IP)</td>
<td>Viscosity</td>
<td>IP_{VISC} = \frac{P_{VISC}}{\sum_{P} P_{VISC}}</td>
</tr>
<tr>
<td>POUR</td>
<td>Vol (IP)</td>
<td>Pour Point</td>
<td>IP_{POUR} = \frac{P_{POUR}}{\sum_{P} P_{POUR}}</td>
</tr>
<tr>
<td>CLOUD</td>
<td>Vol (IP)</td>
<td>Cloud Point</td>
<td>IP_{CLOUD} = \frac{P_{CLOUD}}{\sum_{P} P_{CLOUD}}</td>
</tr>
<tr>
<td>PPFC</td>
<td>Vol (IP)</td>
<td>Plug-Flow Filter</td>
<td>PF = \frac{P_{PF}}{P_{IP}}</td>
</tr>
</tbody>
</table>

CDU: Crude distillation Unit
FCC: Fluid Catalytic Cracking
PDA: Propane Desasphalting
HT: Hydrotreater
**Case 1 – Brazilian Oil-Refining Units Escalation until 2020**

* (aggregated case for conceptual projects refit – only expansion)

**MINLP Model**

- **2016**
  - **2013**

**NPV** = \[ \sum_{t=1}^{T} \left(1 + \frac{r}{100}\right)^{-t} \left( \sum \frac{W_{t,m,d}}{Q_{m,d}} \right) \] - \[ \sum_{t=1}^{T} \frac{1}{1 + \frac{r}{100}} \left( \sum \left( T_{m,d} - T_{m,d} \right) \right) \]

- \( T_{m,d} = \frac{T_{m,d}}{1 + \frac{r}{100}} \)

\( T_{m,d} \) is the time in years.

**Menezes, Moro, Medronho & Pessoa; 2013a,b**

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**Case 2 – São Paulo Supply Chain**

* (non-aggregated case for expansion and installation)

**MILP + NLP Models Decomposed**

**Phenomenological Decomposition Heuristics (PDH)**

**How are the existent processes?**

- **NLP (≤1)** for a feasible (y₁,y₂)
  - Variables: ...

**MILP + NLP**

**QLQC**

- Fixed:... Feed recipes for units/tasks

**Z**

- Interaction for new units

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**EWO Meeting – September 2013**
Next Steps

Structural and temporal decomposition strategies integrated with the phenomenological decomposition heuristics (PDH)

Deal with operational modes to include investments in logistics

Uncertainties?
- Marketing & Sales (demands)
- Purchasing & Procurement
- Fuels Prices Brazil x World
- Projects delays

\[
\frac{(\text{EXCAP} + Q_{\text{new},t-1})}{QC_t}
\]

\(\alpha\) Slope (project velocity)

\(\alpha < 1\) anticipation
\(\alpha = 1\)
\(\alpha > 1\) delay

Project Expected Time/Time