Modeling the Tradeoff between Inventory and Capacity to Optimize Return on Assets in Production Scheduling

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Introduction
Products We Are Dealing With

Fertilizer

Weed Killer
Problem Description

Find out:

• The optimal mix of production capacity and inventory
• At the highest Return on Operating Assets (ROOA)
• In its net present value (NPV)
Methodology

Production Process

Theory of Constraints

Linear Programming Model
Production Process

Pre-mix  Formulation  Storage  Packaging

Theory of Constraints

1st Constraint
2nd Constraint
3rd Constraint
Linear Programming Model

Objective Function

• **Maximize NPV of Return on Operating Assets (ROOA)**

\[
ROOA = \frac{(Revenue_t - Cost_t) \times (1 - Tax)}{Asset\ Value_t}
\]

• **Maximize NPV of Operating Assets Value Add (OAVA)**

\[
OAVA = (Revenue_t - Cost_t) \times (1 - Tax) - Cost\ of\ Capital \times Asset\ Value_t
\]

• Revenue

• Cost
  • Manufacturing
  • Overtime
  • Outsourcing
  • Holding
  • Depreciation

• Asset Value
  • Equipment
  • Inventory
Linear Programming Model

Constraints

- Meet Demand
- Stage Dependence
- Capacity Limit
- Capacity Expansion

- O
- N
The Model’s Outputs

- Master Production Schedule
- Capacity Increase Options and Timing

<table>
<thead>
<tr>
<th></th>
<th>Y1_Jan</th>
<th>Y1_Feb</th>
<th>Y1_Mar</th>
<th>Y1_Apr</th>
<th>Y1_May</th>
<th>Y1_Jun</th>
<th>Y1_Jul</th>
<th>Y1_Aug</th>
<th>Y1_Sep</th>
<th>Y1_Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod (kL)</td>
<td>145</td>
<td>303</td>
<td>432</td>
<td>276</td>
<td>160</td>
<td>403</td>
<td>239</td>
<td>339</td>
<td>952</td>
<td>801</td>
</tr>
<tr>
<td>Prod (kL)</td>
<td>307</td>
<td>644</td>
<td>918</td>
<td>586</td>
<td>340</td>
<td>857</td>
<td>508</td>
<td>720</td>
<td>2023</td>
<td>1703</td>
</tr>
</tbody>
</table>

| Production | Stage (PCK) prod (1) (kL) | 145 | 303 | 432 | 276 | 160 | 403 | 239 | 339 | 952 | 801 |
|           | Stage (PCK) prod (2) (kL) | 307 | 644 | 918 | 586 | 340 | 857 | 508 | 1643 | 1673 | 1824 |
|           | Inv (FG) (1) (kL)         | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
|           | Inv (FG) (2) (kL)         | -   | -   | -   | -   | -   | -   | -   | 924 | 574 | 695 |
|           | Stage (PM&F) prod (1) (kL)| 145 | 303 | 432 | 276 | 160 | 403 | 239 | 339 | 952 | 801 |
|           | Inv (int) (1) (kL)        | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
|           | Stage (PM&F) prod (2) (kL)| 307 | 644 | 918 | 586 | 340 | 857 | 615 | 1786 | 1173 | 1324 |
|           | Inv (int) (2) (kL)        | -   | -   | -   | -   | -   | -   | 107 | 250 | 250 | 250 |
The Model’s Outputs

- Master Production Schedule
- Capacity Increase Options and Timing

<table>
<thead>
<tr>
<th>Pre-Mix &amp; Formulation</th>
<th>Y1_Jan</th>
<th>Y1_Feb</th>
<th>Y1_Mar</th>
<th>Y1_Apr</th>
<th>Y1_May</th>
<th>Y1_Jun</th>
<th>Y1_Jul</th>
<th>Y1_Aug</th>
<th>Y1_Sep</th>
<th>Y1_Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binary (PM&amp;F')</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Binary (PM&amp;F'')</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Binary (PM&amp;F''')</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Validating the Model

- Inventory
  - Expensive vs. Cheap
  - 4 scenarios

“instead of prebuilding the least expensive products, we should prebuild the ones with the Lowest ratio of \( \frac{\text{value}}{\text{processing time}} \) “

Bradley and Arntzen (1999)
Validating the Model

- **Inventory**
  - Expensive vs. Cheap
  - 4 scenarios
    - Baseline
    - PM&F upgrade
    - PCK upgrade
    - Full upgrade
Model Demonstration
Findings
Research Findings

About Increasing Capacity
- Acquiring New Assets
- Overtime
- Outsourcing

About Asset Utilization
Increasing Capacity

Options:
- Acquiring new assets
- Overtime (25% markup)
- Outsourcing (40% markup)

**PM&F Capacity and Production Management in Year 5**

- **Options:**
  - Increasing Capacity
  - Overtime (25% markup)
  - Outsourcing (40% markup)

**Chart Details:**
- **Axes:**
  - Y-axis: Thousands USD
  - X-axis: Months (Jan to Dec)

**Legend:**
- Demand (prod 1)
- P&MF (prod 1)
- OT (PM&F) (prod 1)
- Outsourced (prod 1)
- Demand (prod 2)
- P&MF (prod 2)
- OT (PM&F) (prod 2)
- Outsourced (prod 2)
Increasing Capacity

Options:
- Acquiring new assets
- Overtime (25% markup)
- Outsourcing (40% markup)

PCK Capacity and Production Management in Year 8

Options:
- PM&F
- PCK
- Intermediate 2
- FG2
- Demand
- Raw Materials
- Intermediate 1
- FG1

Options:
- Demand (prod 1)
- P&MF (prod 1)
- OT (PM&F) (prod 1)
- Outsourced (prod 1)

Options:
- Demand (prod 2)
- P&MF (prod 2)
- OT (PM&F) (prod 2)
- Outsourced (prod 2)
### About Asset Utilization

<table>
<thead>
<tr>
<th>Asset Utilization</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Utilization (PM&amp;F)</td>
<td>79%</td>
</tr>
<tr>
<td>Average Utilization (Storage)</td>
<td>25%</td>
</tr>
<tr>
<td>Average Utilization (PCK)</td>
<td>66%</td>
</tr>
<tr>
<td>Holding Cost</td>
<td>$1,583,940</td>
</tr>
<tr>
<td>Manufacturing Cost</td>
<td>$851,769,273</td>
</tr>
<tr>
<td>Outsourcing Cost</td>
<td>$55,372,450</td>
</tr>
<tr>
<td>Overtime Cost</td>
<td>$52,295,046</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$8,791,694</td>
</tr>
<tr>
<td>Proxy Capacity Value</td>
<td>$4,395,847</td>
</tr>
<tr>
<td>Inventory Value</td>
<td>$1,055,960</td>
</tr>
<tr>
<td>10Y NPV OAVA</td>
<td>$123,127,204</td>
</tr>
</tbody>
</table>

Should we maximize asset utilization? **No**
Recommendations

• Combine resources strategically
• Communicate effectively across teams
• Set relevant success metrics
• Use the model wisely
• Revise continuously
Thank you!
Methodology – Setting Up a Linear Programming Model

Objective Function

\[
MAX: \quad Z = \sum_{t=0}^{T} \left( (Revenue_t - Cost_t) \times (1 - Tax) - Cost of Capital \times Asset Value_t \right) \times (1 + r)^t
\]

\[
Revenue_t = \sum_{v_1} \left( D_{t,t} \times \sum_{v_2} (R_{m,t} + L_{m,t} + U_{m,t}) \right) \times F_{rev}
\]

\[
Holding Cost_t = \sum_{v_3} \left( \frac{Inv_{M,t,t-1} + Inv_{M,t-1}}{2} \times \sum_{m=1}^{M} \left( R_{m,t} + L_{m,t} + U_{m,t} \right) \right) \times r
\]

\[
Manufacturing_t = \sum_{v_4} \left( P_{M,t,t} \times (R_{m,t} + L_{m,t} + U_{m,t}) \right)
\]

\[
Outsourcing_t = \sum_{v_5} \left( Out_{t,t} \times \sum_{v_2} (R_{m,t} + (L_{m,t} + U_{m,t}) \times F_{out}) \right)
\]

\[
Overtime_t = \sum_{v_6} \left( Over_{M,t,t} \times (R_{m,t} + (L_{m,t} + U_{m,t}) \times F_{over}) \right)
\]

\[
Depreciation_t = \sum_{v_7} \left( B_{M,t,k} \times \frac{V_{M,k}}{L_M} \right)
\]

\[
Proxy Capacity Value = \frac{1}{n} \times \sum_{t=1}^{n} \sum_{v_2} \left( B_{M,t,k} \times \frac{V_{M,k}}{2} \right)
\]

\[
Inventory Value = \frac{1}{n} \left( \sum_{v_2} \left[ \frac{Inv_{M,t,t} + Inv_{M,t-1}}{2} \times \sum_{m=1}^{M} (R_{m,t} + L_{m,t} + U_{m,t}) \right] \right)
\]

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Methodology – Setting Up a Linear Programming Model

Constraints

- Meet Demand

- Stage Dependence

- Capacity Limit

- Capacity Expansion

- Outsourcing Limit

- Non-Negativity
Acquiring New Assets – PCK

- Objective Function:
- Acquiring assets only after exploiting OT and outsourcing
Acquiring New Assets – PCK

- Objective Function:
  - Acquiring assets only after exploiting OT and outsourcing