Planning Demand and Supply in a Supply Chain

Forecasting and Aggregate Planning

Chapter 8
Aggregate Planning (Ag-gregate: Past part. of Ad-gregare: Totaled)

- If the actual is different than the plan, why bother sweating over detailed plans

- Aggregate planning: General plan for our frequency decomposition
  - Combined products = aggregate product
    - Short and long sleeve shirts = shirt
      - Single product
    - AC and Heating unit pipes = pipes at Lennox Iowa plant
  - Pooled capacities = aggregated capacity
    - Dedicated machine and general machine = machine
      - Single capacity
        - E.g. SOM has 100 instructors
  - Time periods = time buckets
    - Consider all the demand and production of a given month together
      - When does the demand or production take place in a time bucket?
      - Increase the number of time buckets; decrease the bucket length.
Fundamental tradeoffs in Aggregate Planning

Capacity: Regular time, Over time, Subcontract?
Inventory: Backlog / lost sales, combination: Customer patience?

Basic Strategies

- **Chase (the demand) strategy;** produce at the instantaneous demand rate
  - fast food restaurants
- **Level strategy;** produce at the rate of long run average demand
  - swim wear
- **Time flexibility;** high levels of workforce or capacity
  - machining shops, army
- **Deliver late strategy**
  - spare parts for your Jaguar
Matching the Demand

- Use inventory
- Use delivery time
- Use capacity

Adjust the capacity to match the demand

- Which is which?
  Level
  Deliver late
  Chase
  Time flexibility
Capacity Demand Matching
Inventory/Capacity tradeoff

◆ **Level strategy:** Leveling capacity forces inventory to build up in anticipation of seasonal variation in demand

◆ **Chase strategy:** Carrying low levels of inventory requires capacity to vary with seasonal variation in demand or enough capacity to cover peak demand during season
Case Study: Aggregate planning at Red Tomato

- Farm tools:
  - Shovels
  - Spades
  - Forks

Same characteristics?

Generic tool, call it Shovel

Aggregate by similar characteristics
# Aggregate Planning at Red Tomato Tools

80 workers are available on Jan 1.
1000 shovels available on Jan 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1,600</td>
</tr>
<tr>
<td>February</td>
<td>3,000</td>
</tr>
<tr>
<td>March</td>
<td>3,200</td>
</tr>
<tr>
<td>April</td>
<td>3,800</td>
</tr>
<tr>
<td>May</td>
<td>2,200</td>
</tr>
<tr>
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<td>2,200</td>
</tr>
<tr>
<td>Total</td>
<td>16,000</td>
</tr>
</tbody>
</table>
### Aggregate Planning

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>$10/unit</td>
</tr>
<tr>
<td>Inventory holding cost</td>
<td>$2/unit/month</td>
</tr>
<tr>
<td>Marginal cost of a backorder</td>
<td>$5/unit/month</td>
</tr>
<tr>
<td>Hiring and training costs</td>
<td>$300/worker</td>
</tr>
<tr>
<td>Layoff cost</td>
<td>$500/worker</td>
</tr>
<tr>
<td>Labor hours required</td>
<td>4 hours/unit</td>
</tr>
<tr>
<td>Regular time cost</td>
<td>$4/hour</td>
</tr>
<tr>
<td>Over time cost</td>
<td>$6/hour</td>
</tr>
<tr>
<td>Max overtime hrs per employee per month</td>
<td>10 hours</td>
</tr>
<tr>
<td>Cost of subcontracting</td>
<td>$30/unit</td>
</tr>
<tr>
<td>Revenue</td>
<td>$40/unit</td>
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</table>

What is the cost of production per tool? That is materials plus labor.

Overtime production is more expensive than subcontracting.

What is the saving achieved by producing a tool in house rather than subcontracting?
1. Aggregate Planning (Decision Variables)

\[ W_t = \text{Number of employees in month } t, \ t = 1, \ldots, 6 \]
\[ H_t = \text{Number of employees hired at the beginning of month } t, \ t = 1, \ldots, 6 \]
\[ L_t = \text{Number of employees laid off at the beginning of month } t, \ t = 1, \ldots, 6 \]
\[ P_t = \text{Production in units of shovels in month } t, \ t = 1, \ldots, 6 \]
\[ I_t = \text{Inventory at the end of month } t, \ t = 1, \ldots, 6 \]
\[ S_t = \text{Number of units backordered at the end of month } t, \ t = 1, \ldots, 6 \]
\[ C_t = \text{Number of units subcontracted for month } t, \ t = 1, \ldots, 6 \]
\[ O_t = \text{Number of overtime hours worked in month } t, \ t = 1, \ldots, 6 \]

Did we aggregate production capacity?
2. Objective Function:

\[
\text{Min } \sum_{t=1}^{6} 4 \times 8 \times 20 \times W_t + \sum_{t=1}^{6} 300 H_t + \sum_{t=1}^{6} 500 L_t + \sum_{t=1}^{6} 6 O_t + \sum_{t=1}^{6} 2 I_t + \sum_{t=1}^{6} 5 S_t + \sum_{t=1}^{6} 10 P_t + \sum_{t=1}^{6} 30 C_t
\]

3. Constraints

- **Production** (in hours) for each month cannot exceed capacity (in hours)

\[
4P_t \leq 8 \times 20 W_t + O_t \quad \text{or} \quad 40 W_t + O_t / 4 - P_t \geq 0, \quad \text{for } t = 1, \ldots, 6.
\]

- **Workforce size for each month is based on hiring and layoffs**

\[
W_t = W_{t-1} + H_t - L_t, \quad \text{or} \quad W_t - W_{t-1} - H_t + L_t = 0 \quad \text{for } t = 1, \ldots, 6, \quad \text{where } W_0 = 80.
\]
3. Constraints

- Inventory balance for each month

\[ I_{t-1} + P_t + C_t + S_t = D_t + S_{t-1} + I_t, \]
\[ I_{t-1} + P_t + C_t - D_t - S_{t-1} - I_t + S_t = 0, \]

for \( t = 1, \ldots, 6 \), where \( I_0 = 1,000 \), \( S_0 = 0 \) and \( I_6 \geq 500 \).
3. Constraints

- **Overtime for each month**

\[ O_t \leq 10 W_t \text{ or } 10 W_t - O_t \geq 0 \text{ for } t = 1, ..., 6. \]
Execution

- Solve the formulation, see Table 8.3
  - Total cost=$422.275K, total revenue=$640K

- Apply the first month of the plan
- Delay applying the remaining part of the plan until the next month
- Rerun the model with new data next month

- This is called **rolling horizon execution**
Aggregate Planning at Red Tomato Tools

This solution was for the following demand numbers:

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What if demand fluctuates more?
## Increased Demand Fluctuation

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Total costs=$432.858K.

16000 units of total production as before why extra cost?

With respect to $422.275K of before.
Summary

- Qualitative strategies of matching demand and supply
- Quantitative methods
Material Requirements Planning

- Master Production Schedule (MPS)
- Bill of Materials (BOM)
- MRP explosion

Advantages
- Disciplined database
- Component commonality

Shortcomings
- Rigid lead times
- No capacity consideration
Optimized Production Technology

- Focus on bottleneck resources to simplify planning
- Product mix defines the bottleneck(s)?
- Provide plenty of non-bottleneck resources.
- Shifting bottlenecks
Just in Time production

- Focus on timing
- Advocates pull system, use Kanban
- Design improvements encouraged
- Lower inventories / set up time / cycle time
- Quality improvements
- Supplier relations, fewer closer suppliers, Toyota city

- JIT philosophically different than OPT or MRP, it is not only a planning tool but a continuous improvement scheme