Planning Demand and Supply in a Supply Chain

Forecasting and Aggregate Planning
Learning Objectives

- Overview of forecasting
- Forecast errors
- Aggregate planning in the supply chain
- Managing demand
- Managing capacity
Phases of Supply Chain Decisions

- Strategy or design: Forecast
- Planning: Forecast
- Operation: Actual demand

- Since actual demands differs from forecasts so does the execution from the plans.
  - E.g. Supply Chain concentration plans 40 students per year whereas the actual is ??.
Characteristics of forecasts

- Forecasts are always wrong. Should include expected value and measure of error.
- Long-term forecasts are less accurate than short-term forecasts. Too long term forecasts are useless: Forecast horizon
- Aggregate forecasts are more accurate than disaggregate forecasts
  - Variance of aggregate is smaller because extremes cancel out
    » Two samples: (3,5) and (2,6). Averages of samples: 4 and 4.
    » Variance of sample averages=0
    » Variance of (3,5,2,6)=5/2
- Several ways to aggregate
  - Products into product groups
  - Demand by location
  - Demand by time period
Forecasting Methods

- **Qualitative**
  - Expert opinion
  - E.g. Why do you listen to Wall Street stock analysts?

- **Time Series**
  - Static
  - Adaptive

- **Causal**

- **Forecast Simulation for planning purposes**
Components of an observation

Observed demand (O) =
Systematic component (S) + Random component (R)

- **Level** (current deseasonalized demand)
- **Trend** (growth or decline in demand)
- **Seasonality** (predictable seasonal fluctuation)
### Time Series Forecasting

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Demand $D_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>II, 1998</td>
<td>8000</td>
</tr>
<tr>
<td>III, 1998</td>
<td>13000</td>
</tr>
<tr>
<td>IV, 1998</td>
<td>23000</td>
</tr>
<tr>
<td>I, 1999</td>
<td>34000</td>
</tr>
<tr>
<td>II, 1999</td>
<td>10000</td>
</tr>
<tr>
<td>III, 1999</td>
<td>18000</td>
</tr>
<tr>
<td>IV, 1999</td>
<td>23000</td>
</tr>
<tr>
<td>I, 2000</td>
<td>38000</td>
</tr>
<tr>
<td>II, 2000</td>
<td>12000</td>
</tr>
<tr>
<td>III, 2000</td>
<td>13000</td>
</tr>
<tr>
<td>IV, 2000</td>
<td>32000</td>
</tr>
<tr>
<td>I, 2001</td>
<td>41000</td>
</tr>
</tbody>
</table>

*Forecast demand for the next four quarters.*
Time Series Forecasting

![Graph showing time series data with years from 1997.2 to 2000.1 and values ranging from 0 to 50,000.](image-url)
Forecasting methods

- Static
- Adaptive
  - Moving average
  - Simple exponential smoothing
  - Holt’s model (with trend)
  - Winter’s model (with trend and seasonality)
Error measures

- MAD
- Mean Squared Error (MSE)
- Mean Absolute Percentage Error (MAPE)
- Bias
- Tracking Signal
Master Production Schedule

- MPS is a schedule of future deliveries. A combination of forecasts and firm orders.
Aggregate Planning

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

◆ Aggregate planning: General plan
  – Combined products = aggregate product
    » Short and long sleeve shirts = shirt
      ◆ Single product
  – Pooled capacities = aggregated capacity
    » Dedicated machine and general machine = machine
      ◆ Single capacity
  – Time periods = time buckets
    » Consider all the demand and production of a given month together
      ◆ Quite a few time buckets
      ◆ When does the demand or production take place in a time bucket?
Fundamental tradeoffs in Aggregate Planning

- Capacity (regular time, over time, subcontract)
- Inventory
- Backlog / lost sales: Customer patience?

Basic Strategies

- Chase (the demand) strategy;
  - fast food restaurants
- Time flexibility from workforce or capacity;
  - machining shops, army
- Level strategy;
  - swim wear
Matching the Demand

- Use inventory
  - Use delivery time
  - Use capacity

Demands

utdallas.edu/~metin
Aggregate planning at Red Tomato

- Farm tools:
  - Shovels
  - Spades
  - Forks

Are they the same characteristics?

Aggregate by similar characteristics
# Aggregate Planning at Red Tomato Tools

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1,600</td>
</tr>
<tr>
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</tr>
<tr>
<td>March</td>
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</tr>
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</tr>
<tr>
<td>May</td>
<td>2,200</td>
</tr>
<tr>
<td>June</td>
<td>2,200</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 stockout</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>Cost of subcontracting</td>
<td>$30/unit</td>
</tr>
<tr>
<td>Max overtime hrs per employee</td>
<td>10 hours/employee</td>
</tr>
</tbody>
</table>
1. Aggregate Planning (Decision Variables)

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

- **Workforce size for each month is based on hiring and layoffs**
  
  \[
  W_t = W_{t-1} + H_t - L_t, \quad \text{or} \quad W_t - W_{t-1} - H_t + L_t = 0 \quad \text{for } t = 1, \ldots, 6, \text{ where } W_0 = 80.
  \]

- **Production (unit) for each month cannot exceed capacity (hour)**
  
  \[
  P_t \leq 8 \times 20(1/4) W_t + O_t / 4 \quad \text{or} \quad 40 W_t + O_t / 4 - P_t \geq 0, \quad \text{for } t = 1, \ldots, 6.
  \]
3. Constraints

- **Inventory balance for each month**

\[
I_{t-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t,
\]
\[
I_{t-1} + P_t + C_t - D_t - S_{t-1} - I_t + S_t = 0,
\]
for \( t = 1, \ldots, 6 \), where \( I_0 = 1,000 \), \( S_0 = 0 \) and \( I_6 \geq 500 \).

- **Over time for each month**

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

- Solve the formulation, see Table 8.3
  - Total cost=$422,275K, total profit=$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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</tr>
<tr>
<td>May</td>
<td>2,200</td>
</tr>
<tr>
<td>June</td>
<td>2,200</td>
</tr>
<tr>
<td>Total</td>
<td>16,000</td>
</tr>
</tbody>
</table>

What if demand fluctuates more?
### Increased Demand Fluctuation

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<td>3,800</td>
</tr>
<tr>
<td>April</td>
<td>4,800</td>
</tr>
<tr>
<td>May</td>
<td>2,000</td>
</tr>
<tr>
<td>June</td>
<td>1,400</td>
</tr>
<tr>
<td>Total</td>
<td>16,000</td>
</tr>
</tbody>
</table>

Total costs=$432,858K.
Chapter 9:
Matching Demand and Supply

◆ Supply = Demand
◆ Supply < Demand => Lost revenue opportunity
◆ Supply > Demand => Inventory
◆ Manage Supply – Productions Management
◆ Manage Demand – Marketing
Managing Predictable Variability with Supply

Manage capacity

» Time flexibility from workforce (OT and otherwise)
» Seasonal workforce
» Subcontracting
» Counter cyclical products: complementary products
  ◆ Negatively correlated product demands
    – Snow blowers and Lawn Mowers
» Flexible processes: Dedicated vs. flexible

Similar capabilities

One super facility
Managing Predictable Variability with Inventory

» Component commonality
  ◆ Remember fast food restaurant menus

» Build seasonal inventory of predictable products in preseason
  ◆ Nothing can be learnt by procrastinating

» Keep inventory of predictable products in the downstream supply chain
Managing Predictable Variability with Pricing

◆ Manage demand with pricing
  – Original pricing:
    » Cost = $422,275, Revenue = $640,000, Profit=$217,725

◆ Demand increases from discounting
  – Market growth
  – Stealing market share from competitor
  – Forward buying: stealing market share from the future

Discount of $1 increases period demand by 10% and moves 20% of next two months demand forward
Off-Peak (January) Discount from $40 to $39

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3,000=1600(1.1)+0.2(3000+3200)</td>
</tr>
<tr>
<td>February</td>
<td>2,400=3000(0.8)</td>
</tr>
<tr>
<td>March</td>
<td>2,560=3200(0.8)</td>
</tr>
<tr>
<td>April</td>
<td>3,800</td>
</tr>
<tr>
<td>May</td>
<td>2,200</td>
</tr>
<tr>
<td>June</td>
<td>2,200</td>
</tr>
</tbody>
</table>

Cost = $421,915, Revenue = $643,400, Profit = $221,485
Peak (April) Discount from $40 to $39

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</tr>
<tr>
<td>March</td>
<td>3,200</td>
</tr>
<tr>
<td>April</td>
<td>$5,060=3800(1.1)+0.2(2200+2200)</td>
</tr>
<tr>
<td>May</td>
<td>$1,760=2200(0.8)</td>
</tr>
<tr>
<td>June</td>
<td>$1,760=2200(0.8)</td>
</tr>
</tbody>
</table>

Cost = $438,857, Revenue = $650,140, Profit = $211,283
Discounting during peak increases the revenue but decreases the profit!
Demand Management

◆ Pricing and Aggregate Planning must be done jointly

◆ Factors affecting discount timing
  – Consumption: Changing fraction of increase coming from forward buy (100% increase in consumption instead of 10% increase)
  – Forward buy, still 20% of the next two months
  – Product Margin: Impact of higher margin. What if discount from $31 to $30 instead of from $40 to $39.)
January Discount: 100% increase in consumption, sale price = $40 ($39)

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4,440 = 1600(2) + 0.2(3000 + 3200)</td>
</tr>
<tr>
<td>February</td>
<td>2,400 = 0.8(3000)</td>
</tr>
<tr>
<td>March</td>
<td>2,560 = 0.8(3200)</td>
</tr>
<tr>
<td>April</td>
<td>3,800</td>
</tr>
<tr>
<td>May</td>
<td>2,200</td>
</tr>
<tr>
<td>June</td>
<td>2,200</td>
</tr>
</tbody>
</table>

Off peak discount: Cost = $456,750, Revenue = $699,560, Profit = $242,810
Peak (April) Discount: 100% increase in consumption, sale price = $40 ($39)

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<td>January</td>
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<td>3,000</td>
</tr>
<tr>
<td>March</td>
<td>3,200</td>
</tr>
<tr>
<td>April</td>
<td>8,480 = 3800(2) + (0.2)(2200+2200)</td>
</tr>
<tr>
<td>May</td>
<td>1,760 = 0.8 * 2200</td>
</tr>
<tr>
<td>June</td>
<td>1,760 = 0.8 * 2200</td>
</tr>
</tbody>
</table>

Peak discount: Cost = $536,200, Revenue = $783,520
Profit = $247,320
## Performance Under Different Scenarios

<table>
<thead>
<tr>
<th>Regular Price</th>
<th>Promotion Price</th>
<th>Promotion Period</th>
<th>Percent increase in demand</th>
<th>Percent forward buy</th>
<th>Profit</th>
<th>Average Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>$40</td>
<td>$40</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$217,725</td>
<td>895</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>January</td>
<td>20 %</td>
<td>20 %</td>
<td>$221,485</td>
<td>523</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>April</td>
<td>20%</td>
<td>20%</td>
<td>$211,283</td>
<td>938</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>January</td>
<td>100%</td>
<td>20%</td>
<td>$242,810</td>
<td>208</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>April</td>
<td>100%</td>
<td>20%</td>
<td>$247,320</td>
<td>1,492</td>
</tr>
<tr>
<td>$31</td>
<td>$31</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$73,725</td>
<td>895</td>
</tr>
<tr>
<td>$31</td>
<td>$30</td>
<td>January</td>
<td>100%</td>
<td>20%</td>
<td>$84,410</td>
<td>208</td>
</tr>
<tr>
<td>$31</td>
<td>$30</td>
<td>April</td>
<td>100%</td>
<td>20%</td>
<td>$69,120</td>
<td>1,492</td>
</tr>
</tbody>
</table>

Use rows in bold to explain Xmas discounts.
Factors Affecting Promotion Timing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Favored timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>High forward buying</td>
<td>Low demand period</td>
</tr>
<tr>
<td>High stealing share</td>
<td>High demand period</td>
</tr>
<tr>
<td>High growth of market</td>
<td>High demand period</td>
</tr>
<tr>
<td>High margin</td>
<td>High demand period</td>
</tr>
<tr>
<td>Low margin</td>
<td>Low demand period</td>
</tr>
<tr>
<td>High holding cost</td>
<td>Low demand period</td>
</tr>
<tr>
<td>Low capacity volume flexibility</td>
<td>Low demand period</td>
</tr>
</tbody>
</table>
Capacity Demand Matching
Inventory/Capacity tradeoff

- Leveling capacity forces inventory to build up in anticipation of seasonal variation in demand.
  Level strategy

- Carrying low levels of inventory requires capacity to vary with seasonal variation in demand or enough capacity to cover peak demand during season.
  Chase strategy
Deterministic Capacity Expansion Issues

- Single vs. Multiple Facilities
  - Dallas and Atlanta plants of Lockheed Martin
- Single vs. Multiple Resources
  - Machines and workforce
- Single vs. Multiple Product Demands
- Expansion only or with Contraction
- Discrete vs. Continuous Expansion Times
- Discrete vs. Continuous Capacity Increments
  - Can you buy capacity in units of 723.13832?
- Resource costs, economies of scale
- Penalty for demand-capacity mismatch
- Single vs. Multiple decision makers
A Simple Model

No stock outs. $x$ is capacity increments.
Infinite Horizon Total Cost

\[ C(x) = \sum_{k=0}^{\infty} \exp\left(-r(k \frac{x}{\delta})\right)f(x) = f(x)\sum_{k=0}^{\infty} (\exp(-rx/\delta))^k = \frac{f(x)}{1 - \exp(-rx/\delta)} \]

- \( f(x) \) is expansion cost of size \( x \)
- \( C(x) \) is the infinite horizon total discounted expansion cost

\[ f(x) = x^{0.5}; \quad r = 5\%; \quad \delta = 1; \quad \Rightarrow x^* \cong 30 \]

Each time expand capacity by 30-week demand.
Shortages, Inventory Holding, Subcontracting

- Use of Inventory and subcontracting to delay capacity expansions
Stochastic Capacity Planning: 
The case of flexible capacity

- Plant 1 and 2 can produce product A
- Plant 3 can produce product B
- A and B are substitute products
  - with random demands $D_A + D_B = \text{Constant}$
Capacity allocation

- Say capacities are \( r_1 = r_2 = r_3 = 100 \)
- Suppose that \( D_A + D_B = 300 \) and \( D_A > 100 \) and \( D_B > 100 \)

With plant flexibility \( y_{1A} = 1, y_{2A} = 1, y_{3A} = 0, y_{1B} = 0, y_{2B} = 0, y_{3B} = 1 \).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>( D_A )</th>
<th>( D_B )</th>
<th>( X_{1A} )</th>
<th>( X_{2A} )</th>
<th>( X_{3A} )</th>
<th>( X_{1B} )</th>
<th>( X_{2B} )</th>
<th>( X_{3B} )</th>
<th>Shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>50 B</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>200</td>
<td>100</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>100 B</td>
</tr>
</tbody>
</table>
Capacity allocation with more flexibility

- Say capacities are \( r_1 = r_2 = r_3 = 100 \)
- Suppose that \( D_A + D_B = 300 \) and \( D_A > 100 \) and \( D_B > 100 \)

With plant flexibility \( y_{1A} = 1, y_{2A} = 1, y_{3A} = 0, y_{1B} = 0, y_{2B} = 1, y_{3B} = 1 \).

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<td>0</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>150</td>
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</tr>
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<td>200</td>
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<td>0</td>
<td></td>
<td>100</td>
<td>100</td>
<td></td>
<td>0</td>
</tr>
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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
Summary of Learning Objectives

- Forecasting
- Aggregate planning
- Supply and demand management during aggregate planning with predictable demand variation
  - Supply management levers
  - Demand management levers
- MRP, OPT, JIT
- Deterministic Capacity Planning