Outline Chapter 8: Aggregate Planning in the Supply Chain

- Role of aggregate planning in a supply chain
- The aggregate planning problem
- Aggregate planning strategies
- Implementing aggregate planning in practice
Role of Aggregate Planning in a Supply Chain

◆ Basic Assumptions:
  – Capacity has a cost
  – Lead times are greater than zero

◆ Aggregate planning:
  – Is the process by which a company determines levels of capacity, production, subcontracting, inventory, stockouts, and pricing over a specified time horizon
  – goal is to maximize profit  Or, if demand is effectively fixed for all the decision we can make, we can just minimize costs
  – decisions made at a product family (not SKU) level
  – time frame of 3 to 18 months  (What decision phase are we in?)
    » Too late to build another plant
    » Too early to get into daily/weekly production issues, SKU level detail
  – We need to answer: how can a firm best use the facilities it has?
The Aggregate Planning Problem (and role in the Supply Chain)

- The Problem: Given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and the capacity level for each period that maximizes the firm’s (supply chain’s) profit over the planning horizon
  - Specify the planning horizon (typically 3 to 18 months)
  - Specify the duration of each period (typically 1 month for longer horizons)
  - Specify key information required to develop an aggregate plan

- All supply chain stages should work together on an aggregate plan that will optimize supply chain performance
  - For now we ignore transportation issues and costs and have single facility
  - Avoid sub-optimization by silo. We may need to incur more costs (ex. outsourcing production) in a function to maximize overall profit
  - Supply chains usually involve multiple firms. If these firms have close ties, it may be possible to optimize the efficiency of the entire chain
Information Needed for an Aggregate Plan

- Demand forecast in each period
- Production costs
  - Machine costs
  - Labor costs, regular time ($/hr) and overtime ($/hr)
  - Subcontracting costs ($/hr or $/unit)
  - Cost of changing capacity: hiring or layoff ($/worker) and cost of adding or reducing machine capacity ($/machine)
- Labor/machine hours required per unit
- Material requirements per unit, material cost and availability
- Inventory holding cost ($/unit/period)
- Stock-out / backlog cost ($/unit/period)
- Constraints: physical or policy limits on overtime, layoffs, capital available, warehousing, stock-outs and backlogs
Outputs of Aggregate Plan

- **Production quantity** from regular time, overtime, and subcontracted time: used to determine number of workers and supplier purchase levels

- **Inventory held**: used to determine how much warehouse space and working capital is needed

- **Backlog/stock-out quantity**: used to determine what customer service levels can be
  - (i.e. do we short customers for a certain time- and how much/how long?)

- **Machine capacity increase/decrease**: used to determine if new production equipment needs to be purchased

A poor aggregate plan can result in lost sales, lost profits, excess inventory, or excess capacity
Aggregate Planning Strategies

- There is typically a trade-off between optimizing for capacity (machine+labor), inventory, and backlog/lost sales
  - **Chase strategy**: sync production with demand, hiring and firing as needed.
  - **Time flexibility** from workforce or capacity strategy: assumes labor pool can work variable hours (incl. overtime), has lower inventory & utilization,
  - **Level strategy** – keep capacity & labor usage constant, either stockpile inventory or short orders as needed
  - **Mixed strategy** – a combination of one or more of the first three strategies...
Tools for Creating Aggregate Plans

◆ Some companies have not created explicit aggregate plans, and rely only on orders from warehouses or DCs to drive production schedules (pure pull system).
  – This is acceptable only if products are not capacity intensive, or if maintaining a plant with low utilization is inexpensive.
  – It also assumes material and labor inputs are flexible / available when needed

◆ For simple problems, it may be possible to produce a feasible plan by guessing. (No guarantee of optimality)

◆ What tool is commonly used to produce an optimal aggregate plan?
Linear Programming

◆ Inherently assumes costs are linear
  – Pure unit costs are the easiest
  – Increasing marginal costs (e.g. regular labor $20/hour, overtime $30/hour)
  – Economies of scale harder to model, but possible (ignored for this class)

◆ Difficulty of solving increases with degree of detail
  – Take a 1-year plan for a plant that monitors weekly production of 100 different SKUs. *How many variables?*
    » have 100*52 = over 5000 production decision variables $P_{i,t}$
  – If we could aggregate SKUs into 5 different product families, with monthly time buckets, *how many variables do we have now?*
    » only have 5*12= 60 decision variables for $P_{i,t}$
  – Industry aggregate plans often have 10,000 to 100,000 decision variables
    » In this class will keep our problem scales well below that of industry (under 200 decision variables, the limit of the built in Excel solver)
Aggregate Planning Example: Red Tomato Tools, Inc.

- Red Tomato makes a single product, a garden tool that sells for $40
- Red Tomato starts with 1000 of these tools in inventory and is expected to end with at least 500 in stock
- Red Tomato can temporarily backlog demand for a cost, but at the end of the time horizon, they require their backlog to be zero
  - This is an important constraint to remember- if we forget it, we will get strange results
- Production costs are based on parts and labor with no machine capacity issues
  - They start with 80 employees can hire or fire workers for a cost.
  - Workers get regular pay whether they are producing or not. There are 20 days of production per month, each month.
  - We can have workers work overtime (no more than 10 hrs/mo per worker) for extra $
  - We can also subcontract production out and pay a flat fee (in lieu of labor + materials)
- Red Tomato would like to generate a 6 month plan that maximizes profits (revenue net of costs)
  - For now we can just minimizing costs, if we have no influence over demand
Aggregate Planning at Red Tomato Tools

Here’s the demand that the book gives us- *see the seasonality?*

<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>
<td>June</td>
<td>2,200</td>
</tr>
</tbody>
</table>
# Aggregate Planning- Costs

<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/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>
</tbody>
</table>

Note: subcontracting costs includes all materials and labor.

Time to bring up Excel….
Aggregate Planning
(Define the Decision Variables)

\[ W_t = \text{Workforce size for month } t, \ t = 1, \ldots, 6 \]

\[ H_t = \text{Number of employees hired at start of month } t, \ t = 1, \ldots, 6 \]

\[ L_t = \text{Number of employees laid off at start of month } t, \ t = 1, \ldots, 6 \]

\[ P_t = \text{Production in month } t, \ t = 1, \ldots, 6 \]

\[ I_t = \text{Inventory at the end of month } t, \ t = 1, \ldots, 6 \]

\[ S_t = \text{Number of units stocked out (backlogged) at end of month } t, \ t = 1, \ldots, 6 \]

\[ C_t = \text{Number of units subcontracted for month } t, \ t = 1, \ldots, 6 \]

\[ O_t = \text{Number of overtime hours worked in month } t, \ t = 1, \ldots, 6 \]
Aggregate Planning
(Define Objective Function)

\[ \text{Min} \sum_{t=1}^{6} 640 W_t + \sum_{t=1}^{6} 300 H_t \]
\[ + \sum_{t=1}^{6} 500 L_t + \sum_{t=1}^{6} 6 O_t + \sum_{t=1}^{6} 2 I_t \]
\[ + \sum_{t=1}^{6} 5 S_t + \sum_{t=1}^{6} 10 P_t + \sum_{t=1}^{6} 30 C_t \]

Apologies to any Finance gurus but we do not consider NPV here
Aggregate Planning (Constraints)

Aside from the conditions for the ending level of inventory and the ending backlog being $= 0$, we will have 4 other types of constraints to consider:

1. Balance of workers
2. Production limit
3. Balance of inventory
4. Overtime limit
Aggregate Planning (Define Constraints Linking Variables)

- Workforce size for each month is based on hiring and layoffs (\# workers employed end of Month 1 = \# workers employed at the start of Month 2)
  - May end up with fractional \# workers, e.g. 73.4, which could be acceptable if we allow for part-time. *(Also, even if not with larger numbers like this, we can get away with approximating for integer)*
  - Is a **Balance** constraint. No spontaneous creation or destruction of workers outside of the hiring and layoff processes

\[
W_t = W_{t-1} + H_t - L_t, \quad \text{or} \\
W_t - W_{t-1} - H_t + L_t = 0
\]

for \( t = 1, \ldots, 6 \), where \( W_0 = 80 \).
Links Between Periods?

- Why not create 6 different LPs, each with 1 period of a month? It would be easier* for the computer to solve, after all!

- Why not solve several 1-month problems sequentially? At end points, such as #workers left at the end of the month 1 and then use that as the starting #workers for month 2?

* A computer trivial aside from this class: as N increases, the inherent complexity and required solution time goes up by order of N^3 or more)
Aggregate Planning (Constraints)

- Production for each month cannot exceed capacity (hence, have a *limit* rather than *balance* constraint)

\[ P_t \leq 40W_t + O_t/4, \quad \text{or} \]
\[ 40W_t + O_t/4 - P_t \geq 0, \]

for \( t = 1, \ldots, 6 \).
Aggregate Planning (Constraints)

◆ Inventory **balance** for each month.

Inventory levels change if we a) produce (P) or sub-contract (C) more units than we have demand for, either from this period (t) or the prior one (t-1). It may help to think about what is a “debit” and a “credit” to the level of inventory....

\[
I_{t-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t \quad \text{For } t = 1 \text{ to } 6
\]

We can then rearrange the terms to reflect standard form (all variables on one side). What happens at t=0?

\[
I_{t-1} + P_t + C_t - D_t - S_{t-1} - I_t + S_t = 0
\]
Aggregate Planning (Constraints)

- Over-time limit for each month, reflecting policy that no one worker can put in more than 10 hours of overtime for the month.

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

- All of the variables are inherently non-negative

- We have a starting balance of
  - 80 workers
  - 1000 tools
  - 0 backlog

  Thus, the variables associated with these are going to need to be initialized (put in a value for time period 0)

- Reminder: have been told that we are not allowed to have any backlog and must have at least 500 tools in stock at the end of the planning horizon
We now take a brief digression and look at the formulation in Excel, including the LP Solver configuration and the reports.

Some things to think about:
1. How many variables will we have?
2. Which variables have “memory”- and why do we care?
3. How many different types of constraints (aside from non-negativity and certain beginning/end conditions)? How many total constraint equations?
4. What is our overall goal? Why can we take a “shortcut”
### LP Formulation

**Aggregate Plan Decision Variables**

<table>
<thead>
<tr>
<th>Period</th>
<th># Hired</th>
<th># Laid off</th>
<th># Workforce</th>
<th>Overtime</th>
<th>Inventory</th>
<th>Stockout</th>
<th>Subcontract</th>
<th>Product</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>1,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>15</td>
<td>65</td>
<td>0</td>
<td>1,983</td>
<td>0</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>1,567</td>
<td>0</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>950</td>
<td>0</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>0</td>
<td>267</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>117</td>
<td>0</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>500</td>
<td>0</td>
<td>0</td>
<td>2,583</td>
</tr>
</tbody>
</table>

**Aggregate Plan Costs**

<table>
<thead>
<tr>
<th>Period</th>
<th>Hiring</th>
<th>Lay off</th>
<th>Regular Time</th>
<th>Over time</th>
<th>Inventory</th>
<th>Stockout</th>
<th>Subcontract</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1</td>
<td>0</td>
<td>7,708</td>
<td>41,333</td>
<td>0</td>
<td>3,967</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>41,333</td>
<td>0</td>
<td>3,133</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>41,333</td>
<td>0</td>
<td>1,900</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>41,333</td>
<td>0</td>
<td>0</td>
<td>1,333</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>41,333</td>
<td>0</td>
<td>233</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>41,333</td>
<td>0</td>
<td>1,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Total Cost =</td>
<td>$422,275</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Total Revenue</td>
<td>$640,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Decision variables are indexed to 1 thru 6, tp0 exists only for initialization

We have 4 types of constraints, plus 2 ending conditions

Technically we should require variables to be integers (no laying off .2 people or making .3 tools) but for now will leave as linear.
  - Real industry LPs have numbers like 300K and 3M, so this is less of an issue

Assume linear model and non-negativity both checked in Options
What-if Scenarios

- Planners often run re-run their models to see how the plan might change if parameter values are different than expected.

- Here are some potentially realistic changes that would result in changes our previously optimal plan at Red Tomato:
  1. Increase the seasonal swings in demand (Example 8-1)
  2. Raise holding costs (from $2 to $6) (Example 8-2)
## Increased Demand Fluctuation

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1,000</td>
</tr>
<tr>
<td>February</td>
<td>3,000</td>
</tr>
<tr>
<td>March</td>
<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>
</tbody>
</table>

For chapter 8, we are assuming that demand is beyond our control to influence. Demand is still 16000 within the total planning period.
Solution: Comparison of What-If Scenario 1 –vs.- Base Case

◆ Major changes
  – Increases total Costs by $10,583
    » Changes come from Inventory and Stock-out
    » Base Case costs: $10,233 $1,333
    » Larger seasonal fluctuations: $12,400 $9,750

◆ Caveat: The book treats beginning and end periods differently when calculating the average inventory position (see p. 218, p.220). This is overkill: we can just use a simple average if we are interested in the inventory position.
  – Should I ask you to calculate this on a test, either method is correct, but my method is easier!
  – I will focus on minimizing the total inventory COST over the planning horizon rather than inventory LEVELS at any point in time- ultimately, inventory levels are measured because of their associated costs
What-If Scenario #2: Increase Inventory Costs from $2 to $6

- Major changes- costs increase over base case…. In what way?
- Reduce inventory carried by….
  - engaging in more ”workforce reductions” as pre-building inventory for peak periods is no longer as cost effective
  - subcontracting some demand out in peak periods
- We switch from what type of strategy to what?
More Thoughts on Red Tomato’s Planning Problem

1. What if our aggregate demand forecasts are incorrect?
   - Review/Reminder: How often are real forecasts 100% accurate?

2. What if demand is greater than anticipated?
   - What are some ways we can prepare for extra (either in terms of Safety Stock or Safety Capacity?)

3. What if demand is less than anticipated - what will happen?
   - What is one way to keep costs lower if demand is greatly reduced and expected to stay low for awhile?
Managing Supply: Some Possible Tools to Consider

◆ Managing capacity
  – Time flexibility from workforce
  – Use of a seasonal workforce
  – Use of subcontracting
  – Use of dual facilities – dedicated and flexible
  – Designing product flexibility into production processes

◆ Managing inventory
  – Using common components across multiple products
  – Building up inventory of high demand or predictable demand products
  – *Inventory strategies are discussed in detail in Chapters 10-12*
Aggregate Planning in Practice

- **If possible**, think beyond your enterprise to the entire supply chain*

- **Make plans flexible because forecasts are always wrong**
  - Sensitivity Analysis can be used to show where bottlenecks and potential improvements may be

- **Rerun the aggregate plan as new information emerges**
  - Usually every time period, with revisions and future predictions

- **Importance of aggregate planning grows as a firm’s capacity utilization increases**
  - Less room for mistakes in this era of low margins
Summary of Chapter 8’s Learning Objectives

1. What types of decisions are best solved by aggregate planning?
2. What is the importance of aggregate planning as a supply chain activity?
3. What kinds of information are needed to produce an aggregate plan?
4. What are the basic trade-offs a manager makes to produce an aggregate plan?
5. How are aggregate planning problems formulated and solved using Microsoft Excel?
In Chapter 8 we focused on managing supply, but now we are going to consider: Managing demand.

Responding to Predictable Variability in a Supply Chain

- Predictable variability - demand changes that can be forecasted
- Can increase costs and decrease responsiveness in the supply chain (as discussed in Chapter 17- Supply Chain coordination)
- A firm can handle predictable variability using two broad approaches:
  1. Manage **supply** using capacity, inventory, subcontracting, and backlogs (This is what we did in Chapter 8)
  2. Manage **demand** using short-term price discounts and trade promotions
Demand Management

- Promotion- increased marketing, product placements, discounts to wholesalers/retailers, etc.
- Pricing discounts to consumers
- Demand Management and aggregate planning must be jointly coordinated
- Factors that should influence timing of promotion/ price discount
  1. Product margins: Impact of change in margins
  2. Demand changes
  3. Cost of holding inventory
  4. Cost of changing capacity
- Some companies with software or services in this arena: DemandTec, Rapt, KHI
Demand increases can result from a combination of three factors:

1. Market growth (increased sales, increased market size)
2. Stealing market share (increased sales, same market size)
3. Forward buying (same sales, same market size)
   - Have you ever “stocked up” on an item that was on a great sale?
   - Higher demand now offset by demand decrease in later periods

It is crucial to be able to estimate the effect of all these factors, as their effects will determine what is the best pricing and promotion strategy.
Example: Effect of Promotions and Discounts

◆ Red Tomato Example: a $1 discount offered to the consumer for a month is expected to increase demand that period by 10% because of market growth or stealing share, and also with 20% of demand for the next two months being pulled forward to the current month.

◆ How do we compute the new demand?

◆ How do we modify the aggregate planning problem?

◆ Do we need to revisit our objective function?
  – Hint: we are now considering actions that will modify demand between scenarios, whereas in our prior work demand was assumed to be fixed.
Off-Peak (January) if Discount Sales Price from $40 to $39

The next few slides show scenarios from the textbook example

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3,000</td>
</tr>
<tr>
<td>February</td>
<td>2,400</td>
</tr>
<tr>
<td>March</td>
<td>2,560</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>

• 10% increase in January
  • but forward buying decreases Feb and Mar’s demands each by 20%
• Cost = $421,915, Revenue = $643,400, -> Profit = $221,485
• Profit is better than base case (no discount) profit of $217,725
Peak (April) if Discount price from $40 to $39

<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>5,060</td>
</tr>
<tr>
<td>May</td>
<td>1,760</td>
</tr>
<tr>
<td>June</td>
<td>1,760</td>
</tr>
</tbody>
</table>

- 10% increase in April
  - but forward buying decreases May and June’s demands each by 20%
- **Cost = $438,857, Revenue = $650,140, Profit = $211,283**
- Profit is worse than either base case or off-peak discount
January Discount (Sales price $39): if 100% Increase in Consumption

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4,440</td>
</tr>
<tr>
<td>February</td>
<td>2,400</td>
</tr>
<tr>
<td>March</td>
<td>2,560</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>

- Assumest 100% rather than 10% consumption increase
  - either from overall market growth for product or stealing share from others
  - still assume 20% forward buying from Feb and March
- Off-peak discount: Cost = $456,750, Revenue = $699,560, Profit $242,810
Peak (April) Discount: if 100% Increase in Consumption

<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>8,480</td>
</tr>
<tr>
<td>May</td>
<td>1,760</td>
</tr>
<tr>
<td>June</td>
<td>1,760</td>
</tr>
</tbody>
</table>

- We still assume we have 20% forward buying from May and June
- Peak discount: Cost = $536,200, Revenue = $783,520
- PROFIT $247,320 better than no promotion or off peak promo
### 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>
</tr>
</thead>
<tbody>
<tr>
<td>$40</td>
<td>none</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$217,725</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>January</td>
<td>10%</td>
<td>20%</td>
<td>$221,485</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>April</td>
<td>10%</td>
<td>20%</td>
<td>$211,283</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>January</td>
<td>100%</td>
<td>20%</td>
<td>$242,810</td>
</tr>
<tr>
<td>$40</td>
<td>$39</td>
<td>April</td>
<td>100%</td>
<td>20%</td>
<td>$247,320</td>
</tr>
<tr>
<td>$31</td>
<td>none</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$73,725</td>
</tr>
<tr>
<td>$31</td>
<td>$30</td>
<td>January</td>
<td>100%</td>
<td>20%</td>
<td>$84,410</td>
</tr>
<tr>
<td>$31</td>
<td>$30</td>
<td>April</td>
<td>100%</td>
<td>20%</td>
<td>$69,120</td>
</tr>
</tbody>
</table>

- Summary of different results (includes a low-margin variation, where product only retails for a $31 regular price.)
- Based on the effects of different factors, the optimal promotion time (high verses low demand months) will change
Factors Affecting Optimal 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 of market 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>High holding cost</td>
<td>Low demand period</td>
</tr>
<tr>
<td>High flexibility</td>
<td>High demand period</td>
</tr>
</tbody>
</table>

- Reverse timing for opposite (Low Margin -> Low demand period best)
- For a combination of factors (i.e. high margin product, but with a high holding cost) still need to analyze to see which factor dominates
Implementing Solutions to Predictable Variability in Practice

- Coordinate* planning across enterprises in the supply chain
- Take predictable variability into account when making strategic decisions
- Pre-empt (do not just react to) predictable variability
  
  *Be proactive, not reactive*

- Perform a lot of “What-if” analysis BEFORE going live with a strategy!
Summary of Chapter 9’s Learning Objectives

1. What factors may comprise an increase in Demand?
2. How can supply be managed to improve synchronization in the supply chain in the face of predictable variability?
3. How can aggregate planning be used to maximize profitability when faced with predictable variability in the supply chain?