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)

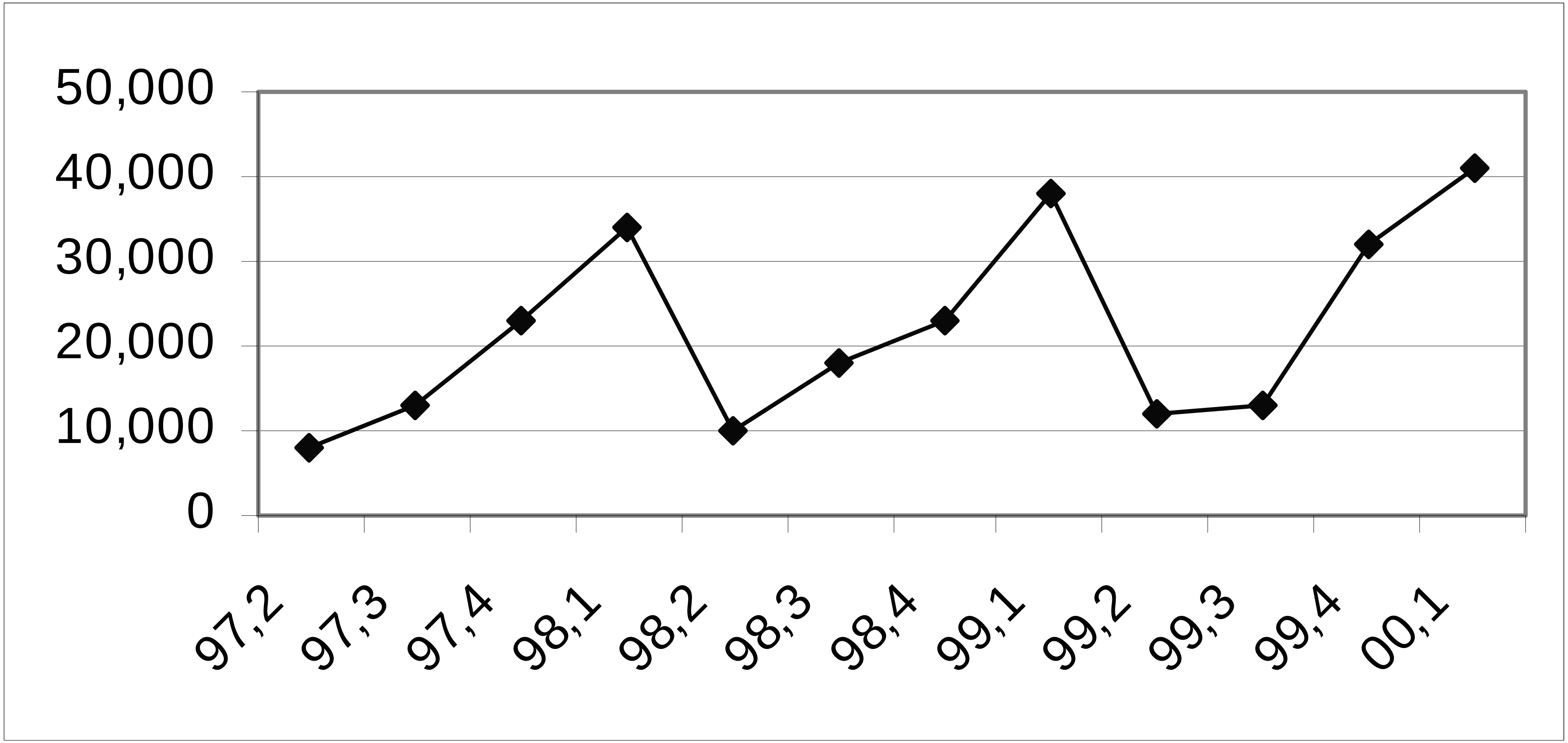
- ***Level*** (current deseasonalized demand)
- ***Trend*** (growth or decline in demand)
- ***Seasonality*** (predictable seasonal fluctuation)

Time Series Forecasting

Quarter	Demand D_t
II, 1998	8000
III, 1998	13000
IV, 1998	23000
I, 1999	34000
II, 1999	10000
III, 1999	18000
IV, 1999	23000
I, 2000	38000
II, 2000	12000
III, 2000	13000
IV, 2000	32000
I, 2001	41000

Forecast demand for the next four quarters.

Time Series Forecasting



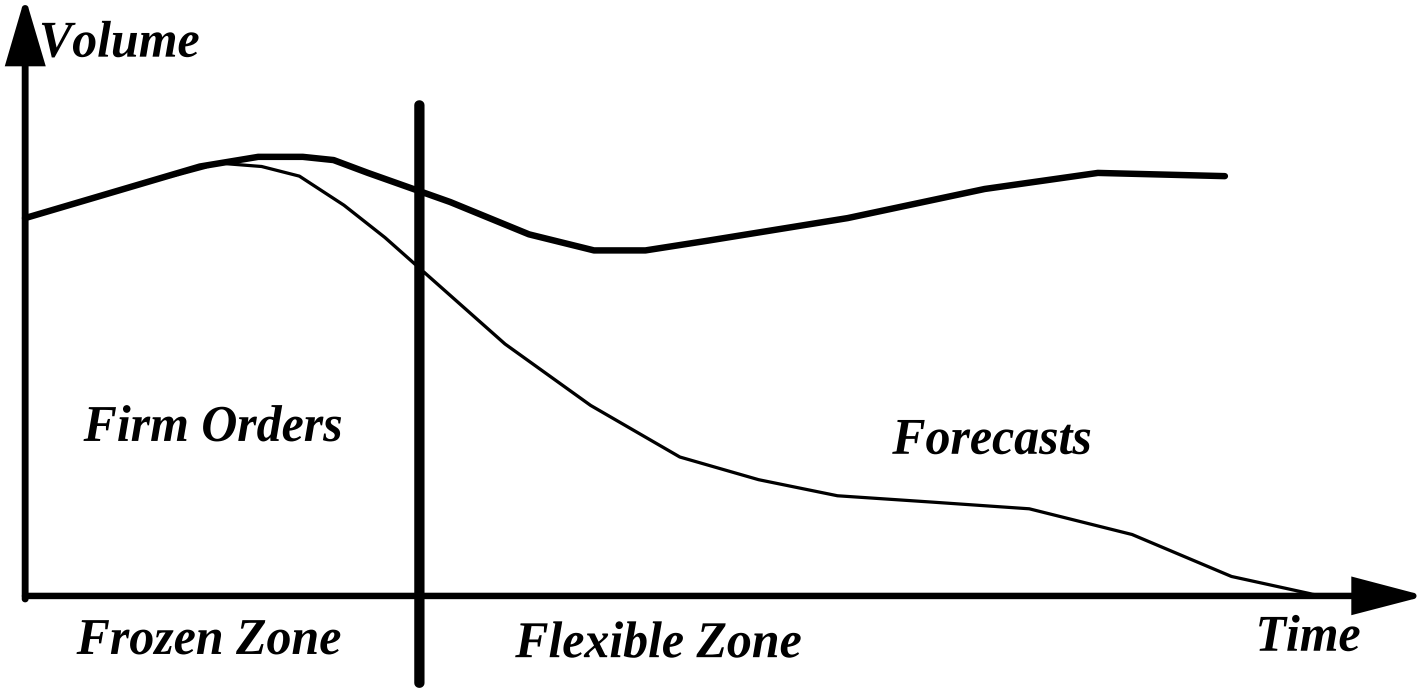
Forecasting methods

- 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?

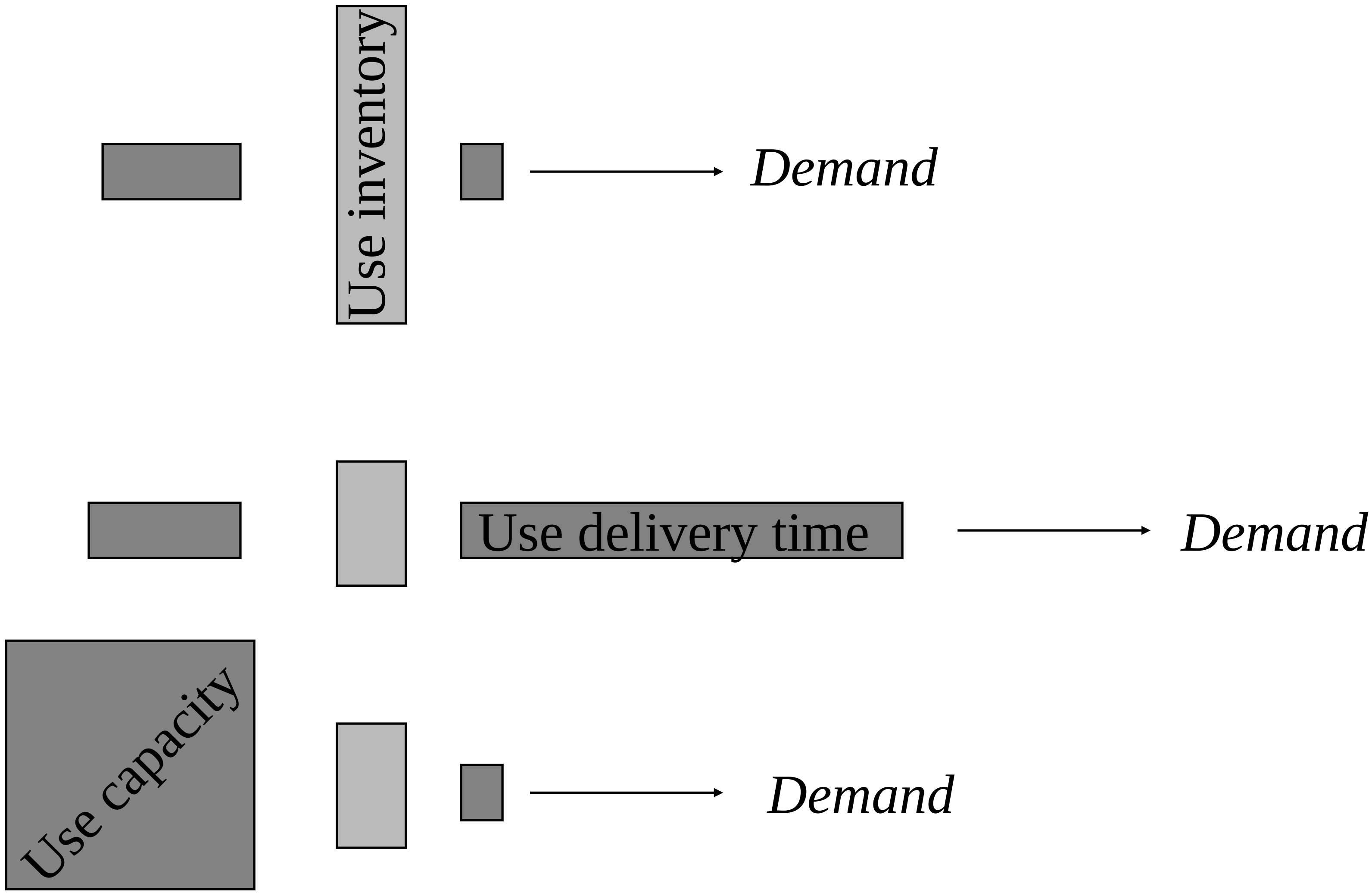
Fundamental tradeoffs in Aggregate Planning

- **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**

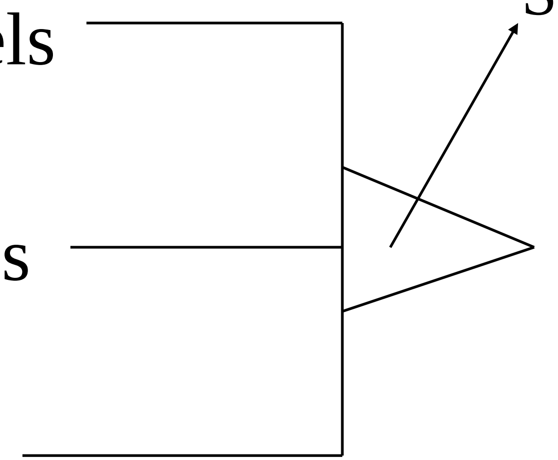
Matching the Demand



Aggregate planning at Red Tomato

- Farm tools:

- Shovels
- Spades
- Forks



Same characteristics?

Generic tool, Shovel

Aggregate by similar characteristics

Aggregate Planning at Red Tomato Tools

Month	***Demand Forecast***
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200

Aggregate Planning

Item	*Cost*
Materials	$10/unit
Inventory holding cost	$2/unit/month
Marginal cost of a stockout	$5/unit/month
Hiring and training costs	$300/worker
Layoff cost	$500/worker
Labor hours required	4hours/unit
Regular time cost	$4/hour
Over time cost	$6/hour
Cost of subcontracting	$30/unit
Max overtime hrs per employee	10hours/employee

1. Aggregate Planning (Decision Variables)

W_t = Workforce size for month *t*, *t* = 1, ..., 6

H_t = Number of employees hired at the beginning of month *t*, *t* = 1, ..., 6

L_t = Number of employees laid off at the beginning of month *t*, *t* = 1, ..., 6

P_t = Production in month *t*, *t* = 1, ..., 6

I_t = Inventory at the end of month *t*, *t* = 1, ..., 6

S_t = Number of units stocked out at the end of month *t*, *t* = 1, ..., 6

C_t = Number of units subcontracted for month *t*, *t* = 1, ..., 6

O_t = Number of overtime hours worked in month *t*, *t* = 1, ..., 6

2. Objective Function:

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

3. Constraints

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

$$W_t = W_{t-1} + H_t - L_t, \quad or$$

$$W_t - W_{t-1} - H_t + L_t = 0 \quad for\ t = 1,\dots,6, \quad where\ W_0 = 80.$$

◆**Production (unit) for each month cannot exceed capacity (hour)**

$$P_t \le 8\times 20(1/4) W_t + O_t / 4 \quad \text{or}$$

$$40 W_t + O_t / 4 - P_t \ge 0, \quad for\ t = 1,\dots,6.$$

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 $t = 1,\dots,6,$ *where* $I_0 = 1{,}000,\ S_0 = 0$ *and* $I_6 \geq 500.$

- **Over time for each month**

$O_t \leq 10W_t$ or

$10W_t - O_t \geq 0$ *for* $t = 1,\dots,6.$

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:

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200
Total	16,000

What if demand fluctuates more?

Increased Demand Fluctuation

Month	*Demand Forecast*
January	1,000
February	3,000
March	3,800
April	4,800
May	2,000
June	1,400
Total	16,000

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)

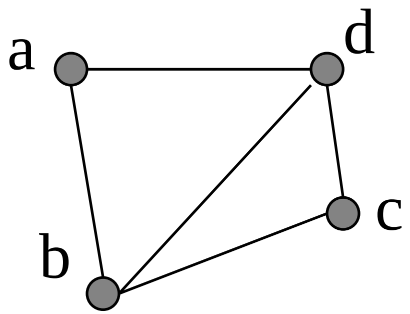
» Seasonal workforce

» Subcontracting

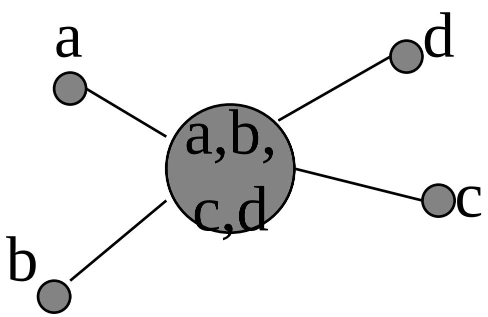
» Counter cyclical products: complementary products

- 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

Month	*Demand Forecast*
January	3,000=1600(1.1)+0.2(3000+3200)
February	2,400=3000(0.8)
March	2,560=3200(0.8)
April	3,800
May	2,200
June	2,200

Cost = $421,915, Revenue = $643,400, Profit = $221,485

Peak (April) Discount from $40 to $39

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	5,060=3800(1.1)+0.2(2200+2200)
May	1,760=2200(0.8)
June	1,760=2200(0.8)

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)

Month	*Demand Forecast*
January	4,440=1600(2)+0.2(3000+3200)
February	2,400=0.8(3000)
March	2,560=0.8(3200)
April	3,800
May	2,200
June	2,200

Off peak discount: Cost = $456,750, Revenue = $699,560
Profit=$242,810

Peak (April) Discount: 100% increase in consumption, sale price = $40 ($39)

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	8,480=3800(2)+(0.2)(2200+2200)
May	1,760=(0.8)2200
June	1,760=(0.8)2200

Peak discount: Cost = $536,200, Revenue = $783,520
Profit=$247,320

Performance Under Different Scenarios

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

Use rows in bold to explain Xmas discounts.

Factors Affecting Promotion Timing

Factor	***Favored timing***
High forward buying	Low demand period
High stealing share	High demand period
High growth of market	High demand period
High margin	High demand period
Low margin	Low demand period
High holding cost	Low demand period
Low capacity volume flexibility	Low demand period

Capacity Demand Matching
Inventory/Capacity tradeoff

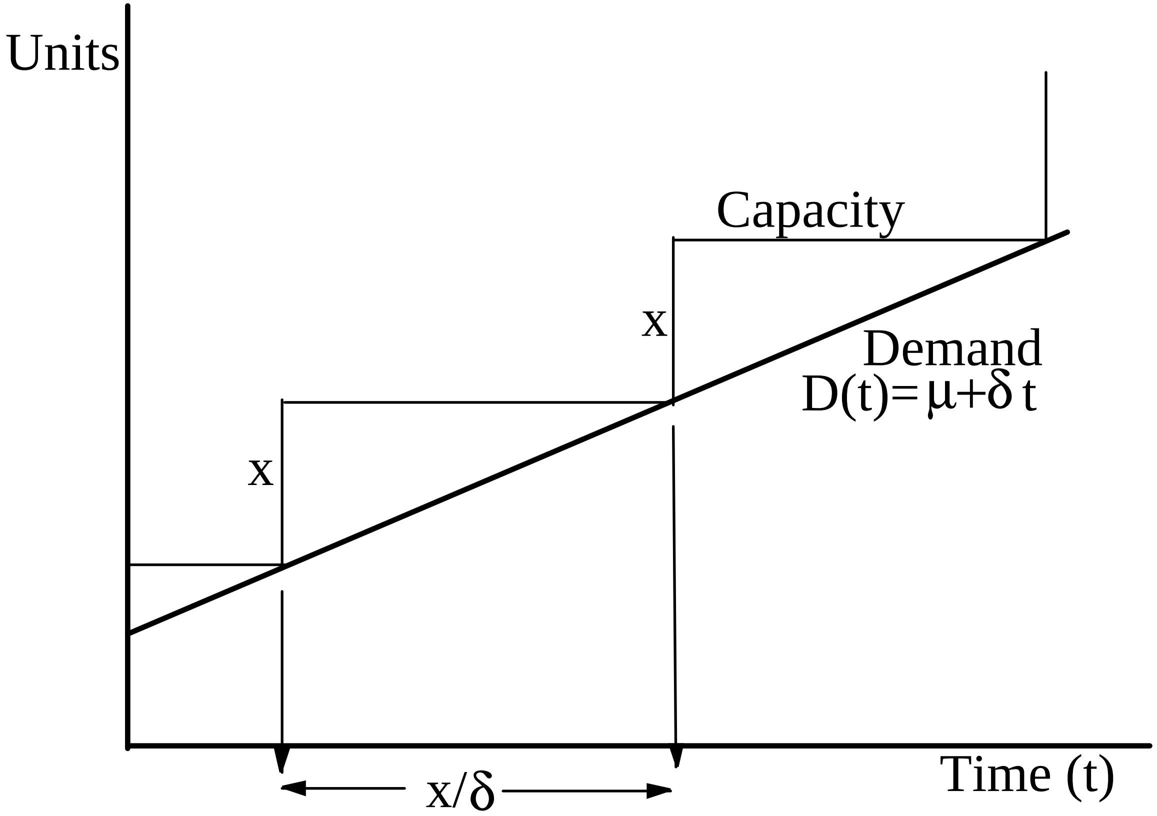
- **Leveling capacity forces inventory to build up in anticipation of seasonal variation in demand**
  Level strategy

- **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

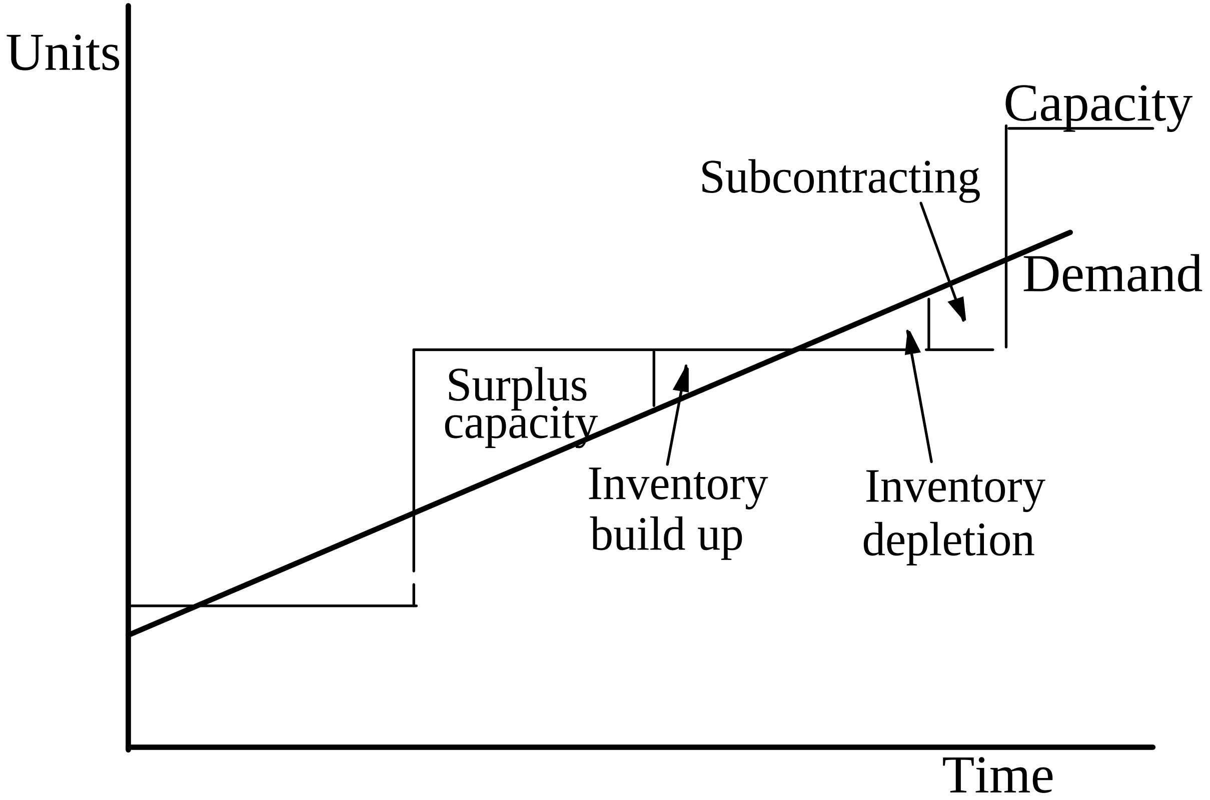
$$C(x) = \sum_{k=0}^{\infty} \exp\left(-r(k\frac{x}{\delta}) \right) f(x) = f(x) \sum_{k=0}^{\infty} (\exp(-rx/\delta))^k = \frac{f(x)}{1-\exp(-rx/\delta)}$$

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

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

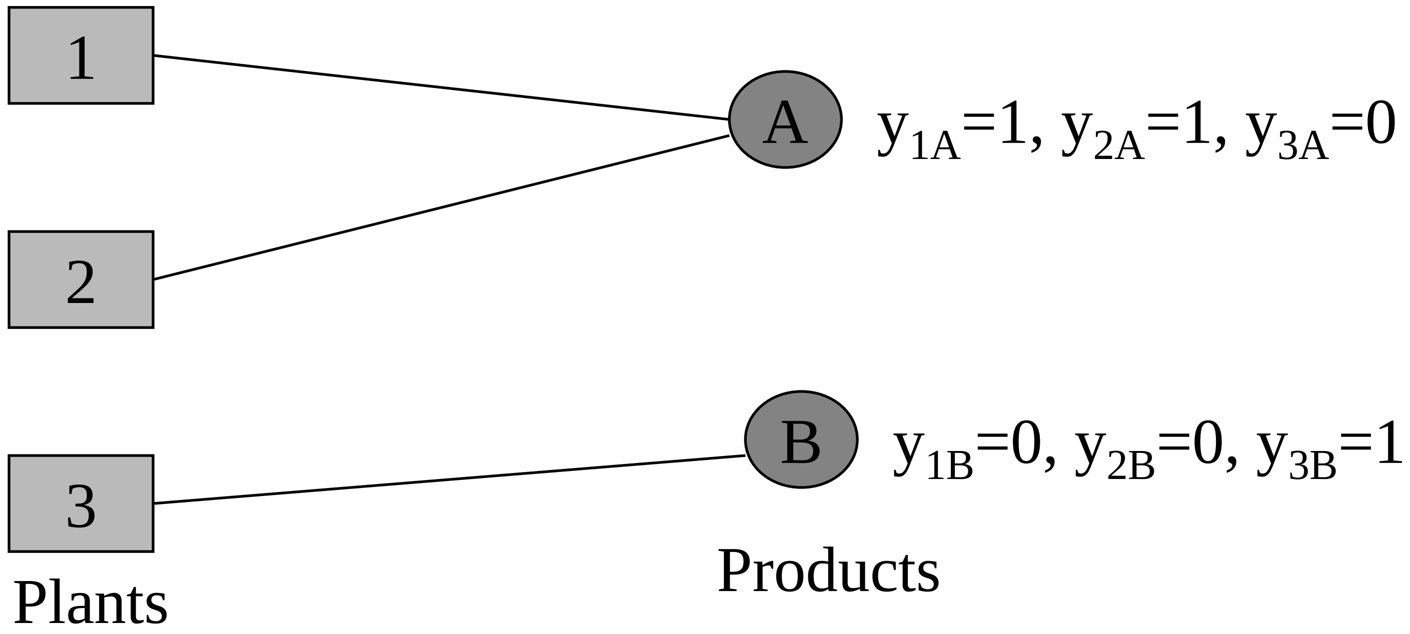
Each time expand capacity by 30-week demand.

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 $D_A + D_B$ = 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 $y_{1A}=1$, $y_{2A}=1$, $y_{3A}=0$, $y_{1B}=0$, $y_{2B}=0$, $y_{3B}=1$.

Scenario	D_A	D_B	X_{1A}	X_{2A}	X_{3A}	X_{1B}	X_{2B}	X_{3B}	Shortage
1	200	100	100	100				100	0
2	150	150	100	50				100	50 B
3	100	200	100	0				100	100 B

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 $y_{1A}=1$, $y_{2A}=1$, $y_{3A}=0$, $y_{1B}=0$, $\mathbf{y_{2B}=1}$, $y_{3B}=1$.

Scenario	D_A	D_B	X_{1A}	X_{2A}	X_{3A}	X_{1B}	X_{2B}	X_{3B}	Shortage
1	200	100	100	100			0	100	0
2	150	150	100	50			50	100	0
3	100	200	100	0			100	100	0

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