Part 3 Process and Supply Chain Operations

Supply chain optimization

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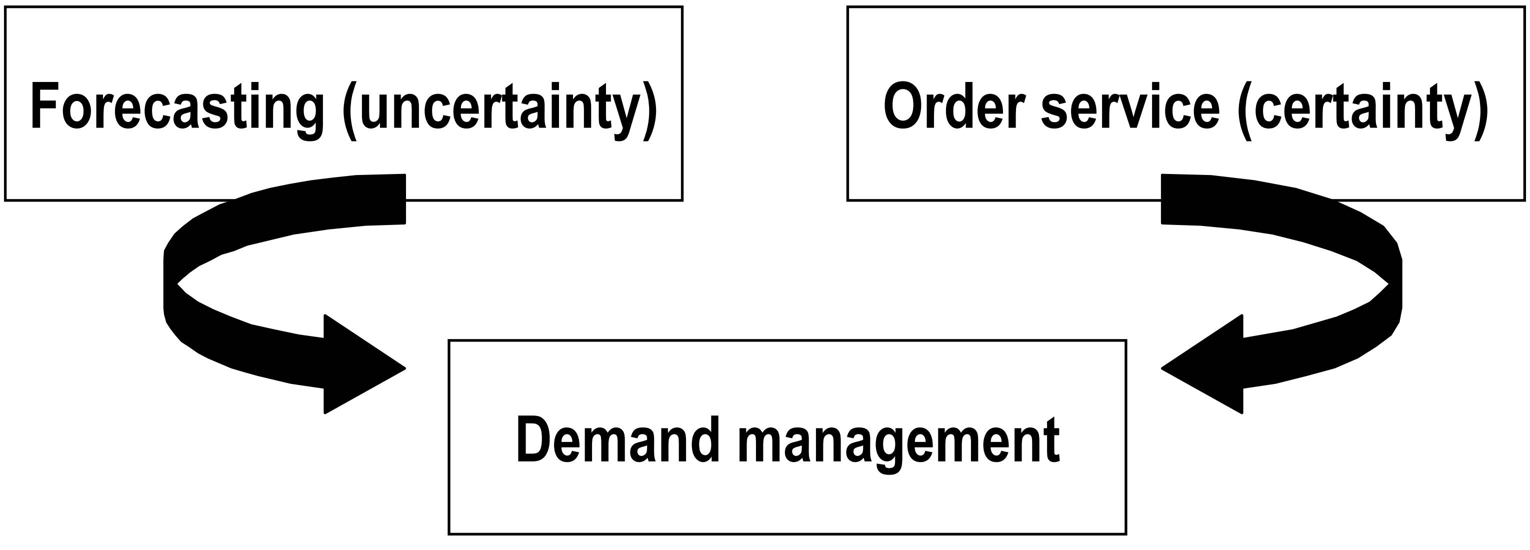
Appendices

Demand Forecast
Transportation Issues
The Role of Inventory

Demand-Management Activities



RULE: Do not forecast what you can plan, calculate, or extract from supply chain feedback.

Source: Adapted from Plossl, "Getting the Most from Forecasts," *APICS 15th International Conference Proceedings*, 1972

Strategies for satisfying customers (Types of Products)

Make-to-Stock	Product shipped from finished goods, “off the shelf” (Examples)
Concerns	What to stock Inventory costs Stock distribution
Make-to-Order	Production initiated after receipt of customer order (Examples)
Concerns	Efficient Manufacturing/Purchasing Production schedules Flexible facilities

Types of Products — Continued

Assemble-to-Order	A make-to-order item where some or all components used in assembly, packaging and finishing processes are planned and stocked in anticipation of a customer order (Examples)
Concerns	What/ How many assemblies to stock Rapid delivery Customized variations

Source: Adapted from Putnam and Wheeler, "Customer Service," 1987.

Customer Service Policy Issues

- Order Responsiveness
  - Volume of order backlog
  - Service level
  - Order lead time required
- Order Scheduling
  - Customer priority rules
  - Resource allocation
- Product Substitution or Upgrade

Source: Adapted from Forgarty et al., Production and Operations Management, 1989

Determining demand - Forecasting

- Forecasts always wrong
  - Expected value and measure of error
- Long term less precise than short term
- More accurate at the aggregate level
  - Example: monthly vs daily expenditure
- The further up the supply chain a company is, the less accurate
    - Bullwhip effect

Forecasting - Main techniques

- Qualitative
  - Management review
  - Delphi method
  - Market research
- Quantitative
  - Moving average
  - Weighted moving average
  - Exponential smoothing
  - Regression analysis
  - Pyramid

Forecasting

- Qualitative
  - Useful on new products: little historical data
  - As a supplement to quantitative numbers
  - Subjective
- Quantitative
  - Needs historical data or projected data
  - Available
  - Consistent
  - Accurate
  - Units - measurable

Work out June's forecasts for all SKU's

SKU	Month					
	Jan	Feb	Mar	Apr	May	Jun
A	25	21	23	2321	21	
B	27	23	26	21	25	
C	16	18	17	23	30	
D	23	26	25	52	23	
E	29	30	?	26	28	
Total	120	118	91	2443	127	

What actions should be taken?

What is forecast for June?

For each SKU? For total?

Simple Moving Averages

Simple Moving Average (SMA)

$$F_{T+1} = \frac{D_T + D_{T-1} + D_{T-2} + \ldots}{n}$$

Where F = Forecast T = Current time period

D = Demand n = Number of periods (max)

Demand	Forecast (3-period)	Forecast (4-period)
180	**start-up**	**start-up**
160	↓	↓
220		
200	186.6	
260	193.3	190
240	226.6	210
	233.3	230

Weighted Moving Averages

Weighted Moving Average (WMA) $F_{T+1} = W_T D_T + W_{T-1} D_{T-1} + \ldots + W_{T-n+1} D_{T-n+1}$

Where: F = Forecast T = Current time period

D = Demand n = Number of periods (max)

W = Weight, where greatest weight applies to most recent period

Demand	Forecast (.2, .3, .5)	Forecast (.1, .2, .3, .4)
180	**start-up**	**start-up**
160	↓	↓
220		
200	194	
260	198	196
240	234	224
	238	236

Exponential Smoothing

➔ Decision

- Select or compute a smoothing constant (α)
- Relationship of exponential smoothing to simple moving average

$$\alpha = \frac{2}{n+1}$$

Where
n = number of past periods to be captured

Formulas

$$F_{T+1} = \alpha\, D_T + (1-\alpha)F_T$$

$$\text{or } F_{T+1} = F_T + \alpha\,(D_T - F_T)$$

Where
F = forecast value
T = current time period
D = demand

Exponential Smoothing —Continued

$$F_{T+1} = F_T + \alpha\,(D_T - F_T)$$

Period	Demand	Forecast ($\alpha = .1$)	Forecast ($\alpha = .5$)	Forecast ($\alpha = .9$)
0	180	start-up	start-up	start-up
1	160	180	180	180
2	220	178	170	162
3	200	182	195	214
4	260	184	198	201
5	240	192	229	254
6		196	234	241

Trended time series forecasting

- Y (**forecast**) = [A (**intercept**) + X (**trend**) x T (**time period**)]
  x S (**seasonality factor**)

- First determine level and trend -
  - if seasonal then de-seasonalize

- Then forecast using exponential or trend

- Re-seasonalize

Simple Trended Series — Example

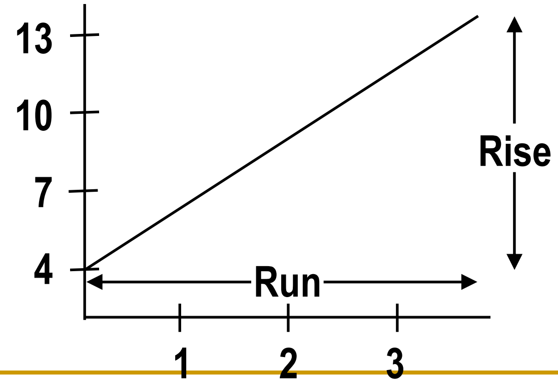
Algebraic Trend Projection

X	Y
0	4
1	7
2	10
3	13

a. Trend ("rise" over "run") = (13 - 4)/3 = 3 = b

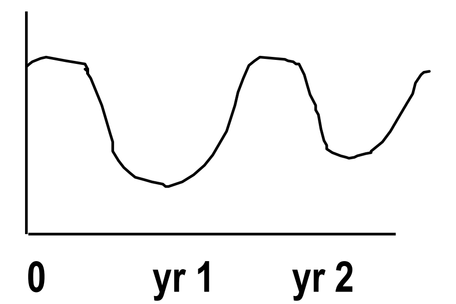
b. Y-intercept (a) = "compute" the Y value for X = 0, thus Y-int = 4

c. Period 4: Y = a + bX = 4 + 3 (4 [for period 4]) = 16



Seasonal Series Indexing Sample Data

Month	Year 1	Year 2	Year 3	Total	Seasonal Index
Jan	10	12	11	33	0.33
Feb	13	13	11	37	0.37
Mar	33	38	29	100	1.00
Apr	45	54	47	146	1.46
May	53	56	55	164	1.64
Jun	57	56	55	168	1.68
Jul	33	27	34	94	0.94
Aug	20	18	19	57	0.57
Sep	19	22	20	61	0.61
Oct	18	18	15	51	0.51
Nov	46	50	45	141	1.41
Dec	48	53	47	148	1.48
Total	395	417	388	1200	12.00



Seasonal

Seasonal Series Indexing Sample Data

Continued

$$\text{Formula: Seasonal Index (SI)} = \frac{\text{Monthly Total (MT)}}{\text{Average Month (AM)}}$$

$$SI_{JAN} = \frac{33}{100} = .33$$

$$SI_{JUL} = \frac{94}{100} = .94$$

Where:

$$AM = \frac{1200}{12} = 100$$

Forecast with Seasonal Indexes and Exponential Smoothing

- Given

	Demand	Deseasonalized Forecast	Seasonal Index
July	34	36	0.94
Aug			0.57

1. Deseasonalize current (July) actual demand $\frac{\text{Actual demand}}{\text{Seasonal index}} = \frac{34}{0.94} = 36.17$

2. Use exponential smoothing to project deseasonalized data one period ahead (α = .2)

$$F_{T+1} = \alpha D_T + (1-\alpha)F_T = (0.2)(36.17) + (0.8)(36) = 36.03$$

3. Reseasonalize forecast for desired month (August)

= Deseasonalized forecast × seasonal factor = 36.03 × 0.57 = 20.53 or 21

Standard Deviation (sigma)

Period	F= Forecast	A = Actual Sales	Error (Sales – Forecast)	Error Squared
1	1,000	1,200	200	40,000
2	1,000	1,000	0	0
3	1,000	800	– 200	40,000
4	1,000	900	– 100	10,000
5	1,000	1,400	400	160,000
6	1,000	1,200	200	40,000
7	1,000	1,100	100	10,000
8	1,000	700	– 300	90,000
9	1,000	1,000	0	0
10	1,000	900	– 100	10,000
	10,000	10,200	200	400,000

Standard Deviation — Continued

Standard Deviation $$\sqrt{\frac{\sum (A_i - F_i)^2}{n-1}} = \sqrt{\frac{400{,}000}{9}} = 211$$

Standard Deviation $$\sqrt{\frac{\sum (A_i - F_i)^2}{n}} = \sqrt{\frac{400{,}000}{10}} = 200$$

NOTE: About the use of n or n - 1 in the above equations

n	Use with a large population (> 30 observations)
n - 1	Use with a small population (≤ 30 observations)

Bias and MAD

Period	F = Forecast	A = Actual Sales	Error (Sales – Forecast)	Absolute Error
1	1,000	1,200	200	200
2	1,000	1,000	0	0
3	1,000	800	– 200	200
4	1,000	900	– 100	100
5	1,000	1,400	400	400
6	1,000	1,200	200	200
7	1,000	1,100	100	100
8	1,000	700	– 300	300
9	1,000	1,000	0	0
10	1,000	900	– 100	100
	10,000	10,200	200	1,600

Cumulative sum of error =

$$\sum\left(A_i - F_i\right) = 200$$

Bias =

$$\frac{\sum\left(A_i - F_i\right)}{n} = \frac{200}{10}$$

Mean Absolute Deviation (MAD)

$$\frac{\sum\left|A_i - F_i\right|}{n} = \frac{1600}{10} = 160$$

Measures of Forecast Error

- Cumulative Sum of Error $$\sum (A_i - F_i)$$
- Bias $$\frac{\sum (A_i - F_i)}{n}$$
- Mean Absolute Deviation (MAD) $$\frac{\sum |A_i - F_i|}{n}$$
- Standard Deviation $$\sqrt{\frac{\sum (A_i - F_i)^2}{n-1}} \quad \text{or} \quad \sqrt{\frac{\sum (A_i - F_i)^2}{n}}$$

NOTE: About the use of n or n - 1 in the above equations

n	Use with a large population (> 30 observations)
n - 1	Use with a small population (≤ 30 observations)

Confidence Intervals

- Definition

  A confidence interval is a measure of distance, increments of which are represented by the **z** value

- Formulas

$$s \text{ (1 Standard Deviation) } = \sqrt{\frac{\sum (A_i - F_i)^2}{n-1}} \quad \textbf{or} \quad \sqrt{\frac{\sum (A_i - F_i)^2}{n}}$$

$$z = \frac{\text{Distance-Mean}}{\text{Standard Deviatiom}} = \frac{x - \overline{x}}{s}$$

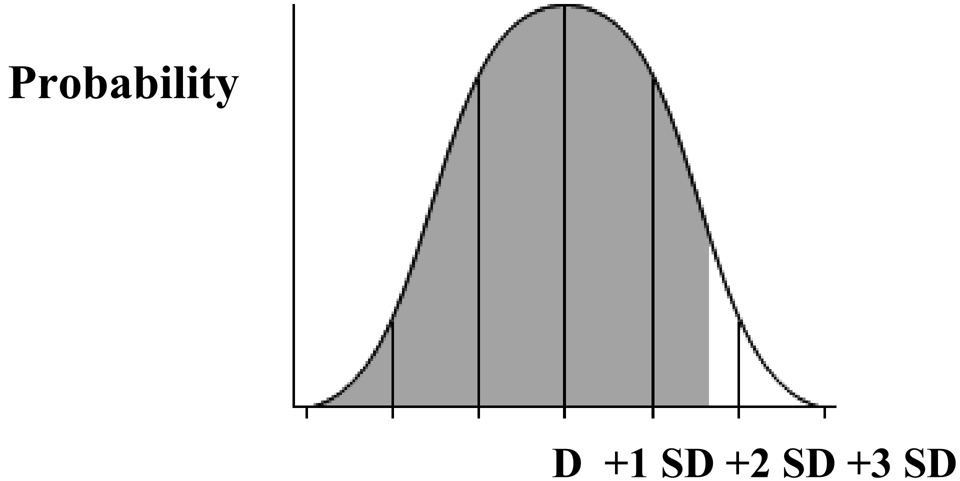
- Relationship

  - 1 standard deviation (σ) = 1.25 × MAD

In the example data σ = 1.25 × 160 = 200

Source: Raz and Roberts, "Statistics," 1987

Expressing z values



Cumulative normal distribution from left side of distribution ($\bar{x}$ + z)

z	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0.0	.5000	.5398	.5793	.6179	.6554	.6915	.7257	.7580	.7881	.8159
1.0	.8413	.8643	.8849	.9032	.9192	.9332	.9452	.9554	.9641	.9713
2.0	.9773	.9821	.9861	.9893	.9918	.9938	.9953	.9965	.9974	.9981
3.0	.9987	.9990	.9930	.9995	.9997	.9998	.9998	.9999	.9999	.9999

Aggregate planning

- Process of determining levels of
  - Production rate
  - Workforce
  - Overtime
  - Machine capacity
  - Subcontracting
  - Backlog
  - Inventory
- Given demand forecast – determine production, inventory/backlog and capacity level for each period
- Fundamental trade-offs
  - Capacity (regular time, overtime, subcontracting)
  - Inventory/service level
  - Backlog/lost sales

Aggregate planning strategies

- Strategies - synchronizing production with demand
  - Chase- using capacity as the lever
    - BY VARYING MACHINE OR WORKFORCE (numbers or flexibility)
    - Difficult to implement and expensive. Low levels of inventory
  - Time flexibility – utilization as the lever
    - IF EXCESS MACHINE CAPACITY, VARYING HOURS WORKED (workforce stable, hours vary)
    - Low inventory and lower utilisation than chase
    - Useful when inventory cost high and capacity cheap
  - Level – using inventory as the lever
    - Stable workforce and capacity
    - Large inventories and backlogs
    - Most practical and popular

Sales and Operations Planning Strategies

	0	1	2	3	4	5	6	7	8	9	10	11	12	Total annual (or period) units
Level Method														
Production		20	20	20	20	20	20	20	20	20	20	20	20	240
Sales		5	5	5	15	25	35	35	35	35	25	15	5	240
Inventory	30	45	60	75	80	75	60	45	30	15	10	15	30	540
Capacity Δ		-	-	-	-	-	-	-	-	-	-	-	-	0
Chase Strategy														
Production		5	5	5	15	25	35	35	35	35	25	15	5	240
Sales		5	5	5	15	25	35	35	35	35	25	15	5	240
Inventory	30	30	30	30	30	30	30	30	30	30	30	30	30	360
Capacity Δ		-	-	-	1	1	1	-	-	-	1	1	1	6

Production Rates and Levels Application 1 — Make-to-Stock

- **Table Format (Inventory)**

Period	0	1	2	3	4
Forecast		150	150	150	150
Production plan					
Inventory	200				100

FOR A LEVEL STRATEGY, WORK OUT THE PRODUCTION PLAN AND INVENTORY BY PERIOD

PRODUCTION = SALES + END INVENTORY – BEGIN INVENTORY

Production Rates and Levels Application 2 — Make-to-Order

- **Table Format (Backlog)**

Period	0	1	2	3	4
Forecast		150	150	150	150
Production plan					
Backlog	200				100

FOR A LEVEL STRATEGY WORK OUT THE PRODUCTION PLAN AND BACKLOG BY PERIOD

PRODUCTION = SALES + BEGIN BACKLOG - END BACKLOG

Optimization thru linear programming

- AGGREGATE PLANNING MODEL
  - Maximizing highest profit over time period
  - Determine decision variables pp107
  - Objective function – minimize total cost
    - DEVELOP EQUATIONS FOR ALL THE COST ELEMENTS
  - Constraints equations
    - Workforce
    - Capacity
    - Inventory
    - Overtime
  - Optimize objective function
  - Forecast error
    - Safety inventory
    - Safety capacity

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

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	4/unit
Regular time cost	$4/hour
Over time cost	$6/hour
Cost of subcontracting	$30/unit

Aggregate Planning (Objective Function)

LABOR COST

REGULAR **OVERTIME** **HIRING COST** **LAYOFF COST**

$$Min \quad \sum_{t=1}^{T} CRT_t \cdot W_t + \sum_{t=1}^{T} COL_t \cdot O_t + \sum_{t=1}^{T} CHI_t \cdot H_t + \sum_{t=1}^{T} CLA_t \cdot L_t +$$

$$\sum_{t=1}^{T} CIN_t \cdot I_t + \sum_{t=1}^{T} CSO_t \cdot S_t + \sum_{t=1}^{T} CRM_t \cdot P_t + \sum_{t=1}^{T} CSU_t \cdot C_t$$

INVENTORY COST **STOCK-OUT COST** **MATERIAL COST** **SUBCONTRACTING COST**

Aggregate Planning (Constraints)

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

$$W_t - W_{t-1} - H_t + L_t = 0 \qquad t = 1,\ldots,T$$

- Production for each month cannot exceed capacity

$$UW \cdot W_t + O_t / LH - P_t \geq 0 \qquad t = 1,\ldots,T$$

- Inventory balance for each month

$$I_{t-1} + P_t + C_t - D_t - S_{t-1} - I_t + S_t = 0 \qquad t = 1,\ldots,T$$

- Over time for each month

$$U \cdot W_t - O_t \geq 0 \qquad t = 1,\ldots,T$$

Aggregate planning in practice

- Make plans flexible because forecasts are always wrong
  - Perform sensitivity analysis on the inputs – I.E. Look at effects of high/low
- Rerun the aggregate plan as new data emerges
- Use aggregate planning as capacity utilization increases
  - When utilization is high, there is likely to be capacity limitations and all the orders will not be produced

Managing supply and demand predictable variability

- Predictable variability – change in demand can be forecast
  - MANAGING DEMAND – short time price discounts, trade promotions
  - MANAGING SUPPLY – capacity, inventory, subcontracting & backlog, purchased product
  - Managing capacity
    - Time flexibility from workforce (overtime)
    - Use of seasonal workforce
    - Use of subcontracting
    - Use of dual facilities – dedicated and flexible
    - Design product flexibility into production
    - Use of multi-purpose machines (cnc machine centers)
  - Managing inventory
    - Using common components across multiple products
    - Build inventory of high demand or predictable demand

Supplier partnerships

- Qualification and selection
  - Rationalization of supplier base
- Partnership
  - Win-win and trust
  - Sharing of risk and commitment
  - Price reductions **and** increases based on forecast
  - Rate replenishment
- Measurement and feedback
  - Quality, delivery, responsiveness
  - Quarterly feedback
  - Implications

Managing demand (predictable variability)

- Manage demand with pricing
  - Factors influencing the timing of a promotion:
    - Impact on demand; product margins; cost of holding inventory; cost of changing capacity
- Demand increase (from discounting) due to:
  - Market growth
  - Stealing market share
  - Forward buying

Discount of $1 increases period demand by 10% and moves 20% of next two months demand forward

Reduce price by $1in Jan or April, increase sales by 10%

Process Flow Measures

- FLOW RATE (R_t), CYCLE TIME (T_t), & INVENTORY (I_t) RELATIONSHIPS
  - F = Flow Rate or Throughput is output of a line in pieces per time
  - T = Cycle time is the time taken to complete an operation
  - I = Inventory is the material on the line
  - **LITTLE's LAW:**

    Av. I = Av. R x Av. T x Variability factor
  - **Examples:**
    - If Inventory is 100 pieces and Cycle time is 10 hours, the Throughput rate is 10 pcs per hour
    - If Cycle time is halved; Throughput is doubled
    - If Inventory is halved; cycle time is halved

Make-or-Buy Decision

- Cost
- Time
- Capacity Utilization
- Control of Production/Quality
- Design Secrecy
- Supplier Reliability and Technical Expertise
- Volume
- Workforce Stability

Make-or-Buy Decision

- **Original Data:**

Produce 10,000 units

Cost Factors

Raw material	$9,000
Direct labor	$12,000
Variable factory overhead	$5,000
Fixed factory overhead	$24,000
Total Cost to Make	**$50,000**

Make cost per unit = $50,000/10,000 = $5.00/unit

Purchase proposal = $4.50/unit

Should the product be bought?

Factors to Consider:

1. You only avoid 80% of the variable factory overhead cost
2. And only avoid 10% of the fixed factory overhead cost

Cost Avoidance Analysis (Solution)

Solution	
Cost avoided by purchasing	
Total cost to make	**$50,000**
Less cost avoided:	
Raw material	$9,000
Direct labor	$12,000
Variable factory overhead ($5,000@0.80)	$4,000
Fixed factory overhead ($24,000@0.10)	$2,400
Total Avoided Cost	**$27,400**
Analysis	
Cost not avoided	$22,600
Plus cost to purchase	$45,000
Total cost to purchase	**$67,600**
Compare to cost to make	$50,000
Increase in cost to purchase	**$17,600**
Actual cost per purchased item	**67500/1000 = $6.75/unit !**

Manufacturing - managing lead time

- Critical driver of all manufacture
  - Layout and workplace organization
  - Constraint management
  - Variability and queues
  - Lot sizes and set up reduction
  - Work in process
  - Flexibility
- Must be company focus
- Measured and monitored
  - X butt to butt

Managing inventory

- The role of inventory in the supply chain
  - Cycle Inventory takes advantage of economies of scale to lower total cost – material cost, fixed ordering cost and holding cost.
- Why hold inventory?
  - Economies of scale
    - Batch size and cycle time
    - Quantity discounts
    - Short term discounts / Trade promotions
  - Stochastic variability of supply and demand
    - Evaluating service level given safety inventory
    - Evaluating safety inventory given desired service level
- Levers to improve performance

Predictable variability in practice

- Coordinate marketing, sales and operations
  - Sales and operations planning
  - One goal maximizing profit, one game plan
- Take predicable variability into account when making strategic decisions
- Partner with principal customers, eliminate predictions!
- Preempt (promos etc.). Do not just react to predictable variability