Logistics System *– 2008, S.O. @MIT*

DEMAND PLANNING/ FORECASTING

- The truth about forecasting and suggestions

Truth	Suggestions
1. The forecast is "always" wrong • Statistical errors • Difference between past and future	• Range forecasting • Flexible contracts

2. Aggregated forecasts are more accurate	• Risk pooling
	  ○ product distribution
	  ○ parts
	  ○ product variety

3. Forecasts over short time horizon are more accurate	• Postponement • Concurrent process
4. Long history helps	• Test sales to create history
5. Trading partner have information	• Collaboration/ tightening
6. Risk sharing can mitigate the consequences	• Joint new product development • Joint ventures • Supply contract

- 4 fundamental approaches

Subjective	Objective
1. Judgmental • Sales force survey • Jury of experts	3. Time series • "Black Box" approach • Uses past to predict future
2. Experimental • Customer surveys/ Focus group • Test marketing • Simulation	4. Causal/ Relational • Econometric model • Leading indicators • Input – Output • Run regressions!

- Time Series

Good for…	Bad for…
• Short term • Mature products • SKU level	• New or dying products • Short life-cycle products • Erratic sparse demand

    - Variables
        - Level (a)
        - Trend (b)
        - Seasonality variations (F)
        - Cyclical movements (c)
        - Random fluctuations
    - Methods
        - Moving Average
        - Exponential Smoothing - value of observation degrades overtime
            - $X_{t,\,t+1} = \alpha X_t + (1-\alpha)X_{t-1,\,t}$ $0.01<\alpha<0.3$ (≈ 0.1)
        - Level and Trend
            - $X_{t,\,t+1} = a_t + tb_t$

- $a_t = \alpha X_t + (1-\alpha)(a_{t-1} + b_{t-1})$ 0.02<α<0.51 (≈0.19)
- $b_t = \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1}$ 0.005< β <0.176 (≈0.053)

  - Level, Trend and Seasonal
    - $X_{t,t+T} = (a_t + Tb_t) F_{t+T-p}$
    - $a_t = \alpha(X_t / F_{t-p}) + (1-\alpha)(a_{t-1} + b_{t-1})$
    - $b_t = \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1}$ 0.005< β <0.176 (≈0.053)
    - $F_t = \gamma(X_t / a_t) + (1-\gamma) F_{t-p}$ 0.05< γ <0.5 (≈0.1)

- Forecast Evaluation
  - Accuracy
    - Forecast Error $e_t = X_t - X^{\bar{}}_t$
    - Mean Deviation $MD = \sum e_t/n$
    - Mean Absolute Deviation $MAD = \sum|e_t|/n$
    - Mean Squared Error $MSE = \sum e^2_t/n$
    - Root Mean Squared Error $RMSE = sqrt(\sum e^2_t/n)$
    - Mean Absolute Percent Error $MAPE = \sum(|e_t|/D_t)/n$
  - Bias
    - Cumulative Sum of Error (Ct) …normalized by dividing by RMSE
    - Smoothed Error Tracking Signal …$T_t = z_t/ MAD_t$, where $z_t = we_t + (1-w)z_{t-1}$
    - Auto Correlation of Forecast Errors

<u>INVENTORY PLANNING & MANAGEMENT</u>

- Why Hold Inventory
  - Buffer for demand/ supply spikes
  - Minimize cost (ordering, shortage)
  - Speculation/ Anticipation for purchasing price change
  - Cover process time
- Inventory Decisions = Supply chain decision + Deployment decision + Replenishment decision
- Inventory Fundamentals
  - TC = Purchase + Ordering + Holding + Shortage

    $vD + A(D/Q) + (Q/2+k\sigma)vr + B_1(D/Q)P_{u\geq(k)}$ or $B_2(D/Q)v\sigma_L G_{u(k)}$
  - Variables
    - D = Ave demand (units/ unit time)
    - A = Fixed ordering cost ($/ order)
    - v = Variable cost – purchase, shipping ($/ unit)

  - r = Carrying ($/ $ held/ time)
  - Q = Replenishment order quantity (units/ order)

- EOQ (Economic Order Quantity)
  - Basic Model
    - EOQ = sqrt (2AD/ vr), TRC[EOQ] = sqrt (2Advr)
  - w/ order leadtime <u>L</u> …Order EOQ when IOH = DL (refer to (R, S) policy)
  - w/ finite replenishment – inventory becomes available at rate of <u>m</u> units/ time
    - TRC[Q] = A(D/Q) + Q(1-D/m)vr/ 2
    - EOQ = sqrt (2AD/ vr(1-D/m))
  - w/ multiple locations – <u>n</u> locations
    - EOQ = sqrt (2AD/ vrn), IOH = sqrt(n)*Q/2
  - w/ all unit discount
    - if $Q>Q_b$, $v = v_0(1\text{-}d)$, otherwise $v = v_0$
    - if $Q>Q_b$, TRC = $Dv_0(1\text{-}d) + A(D/Q) + v_0(1\text{-}d)rQ/2$
  - w/ incremental discount
    - 4 Steps
      1. Find Fixed Cost per breakpoint, F_i, for each break
      2. Find EOQ_i for each range… EOQ = sqrt $(2D(A+F_i)/ rv_i)$
      3. If EOQ_i is not within allowable range, go to next I. Otherwise, find TRC_i using effective cost per unit, v_{ei}
      4. Pick EOQ_i with lowest TRC
    - $F_i = F_{i-1} + (v_{i-1} – v_i)Q_i$, $F_0 = 0$

- Stock Out Cost
  - E[Unit Short]/ cycle = $\sigma_{L+R}\, G_{(k)}$
  - Cost minimization perspective
    - B1: Cost per stock out <u>event</u> ($/ event)

        - Stock out cost = $B_1(D/Q)P_{u\geq(k)}$
        - $K = sqrt(2ln*(DB_1/ sqrt(2\pi)Qvr\sigma_L))$
      - B2: Cost per stock out <u>item</u> (% of v)
        - Stock out cost = $B_2(D/Q)v\sigma_L G_{u(k)}$
        - $P_{u\geq(k)} = Qr/DB_2$
  - Service level maximization perspective
    - P_1: CSL (Cycle Service Level)
      - Probability of no stock outs per replenishment cycle
      - CSL = $1- P_{u\geq(k)}$
    - P_2: IFR (Item Fill Rate)
      - Fraction of demand filled from IOH (usually much higher than CSL for given ss)
      - When 100% back order, IFR = $1 – \sigma_L G_{(k)}/Q$, $G_{(k)} = Q/\sigma_L(1 – IFR)$
        - IFR = (Q- E[Unit Short])/ Q
        - E[Unit Short] = $1 – \sigma_L G_{(k)}/Q$
      - When lost sales, IFR = $Q/(Q+ \sigma_L G_{(k)})$, $G(k) = Q/\sigma_L*(1 – IFR)/IFR$

ss	k	$P_{u\geq(k)}$	$G_{(k)}$
↑	↑	↓	↓
↓	↓	↑	↑

- Inventory Policy & Item Type

Item Type	Continuous Review	Periodic Review
A	(s, S)	(R, s, S)
B	(s, Q)	(R, S)
C		Manual ~ (R, S)

  - B Item
    - (s, Q) policy
      - Q= EOQ
      - s (reordering point) = X_L (cycle stock) + $k\sigma_L$ (safety stock)
        - k = ss factor – implies service level and stock out cost

        - σ_L = RMSE of demand forecast errors (or stdv of demand)
    - (R, S) policy
      - Q= DR
      - s= S= $X_{L+R} + k\sigma_{L+R}$
      - Ordering cost = A/R …e.g. if R=1month and A is X units/ yr, 12X
  - A Item
    - Fast Moving …small v, large Q
      - Solve k* and Q* simultaneously
        - Q* = EOQ*sqrt(1+$B_1 P_{u\geq(k)}$/A)
        - K* = sqrt(2ln*(DB_1/ sqrt(2π)Qvrσ_L))
      - Policy = (s, S) or (R, s, S)
    - Slow Moving …large v, Q=1
      - E[Unit Short] = (1-IFR)λ … Poisson Distribution
      - $L(X_0) = \lambda$ => $L(X_1) = L(X_0) - (X_1 - X_0)(1-F(X_0))$
  - C Item
    - Periodic review rather than continuous
    - Look to reduce the number of orders (synchronize R across SKUs)
    - Decision rule: how much for disposal = IOH – EOQ – D(v-salvage)/(vr)
- News Vendor Model
  - Variables
    - R = Retail price
    - W = Whole sale price (= cost for retailer)
    - C = Cost (= manufacturer price)
    - S = Salvage cost
    - B = Penalty for not covering demand

- Optimal order for each players
  - Retailer's perspective
    - Critical ratio = P(Demand ≤ Q_R*) = (R-W+B)/(R-S+B)
    - Find k as $P_{u\geq(k)}$ = (W-S)/(R-S+B)
    - Q_R* = E[D] + kσ_D
    - E[Profit] = R*E[D] + S*E[Unsold] – Rσ_DG(k) – C*Q

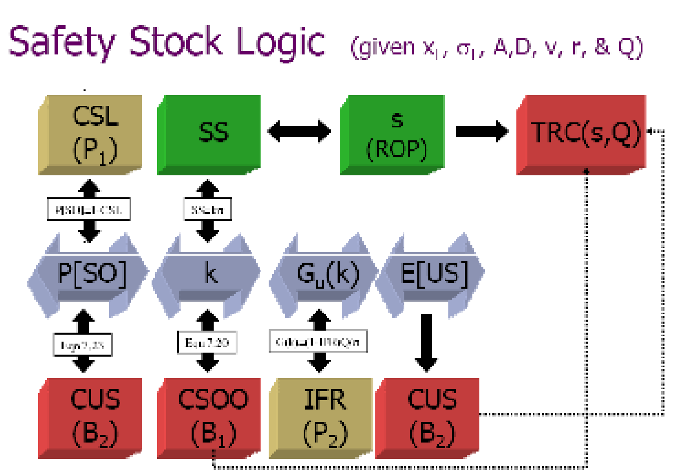
      = (R-S)E[D] – (C-S)Q – (R-S) σ_DG((Q-E[D])/ σ_D)
  - Whole seller's perspective
    - D = Q_R
    - E[Profit] = (W-C) Q_R
  - Channel's perspective
    - Critical ratio = P(Demand ≤ Q_C*) = (R-C+B)/(R-S+B)
- Procurement contracts for optimization
  - Buyback contract – set buyback price <u>P</u> so as to have Q_R* = Q_C*

    ⇨ (R-W)/(R-<u>P</u>) = (R-C)/(R-S)

    ⇨ P = W(R-S)/(R-C) – R(C-S)/(R-C)
  - Revenue Share – set <u>p</u> so as to have Q_R* = Q_C*

    ⇨ (<u>p</u>R-W)/(<u>p</u>R-B) = (R-C)/(R-S)

    ⇨ p = W(R-S)/ (R(C-S)) – S(R-C)/ (R(C-S))



TRANSPORTATION DESIGN, PROCUREMENT & MANAGEMENT

- Transportation Fundamentals
  - Type of network
    - Physical network
    - Operational network
    - Strategic network
  - Transportation products
    - 4 primary transportation components
      - Loading/ unloading
      - Line-haul
      - Local-routing
      - Sorting
    - 3 driving influences
      - Economies of scale
      - Economies of scope …balance, utilization of return trip
      - Economies of density …ave d_{stop}
- Implication of Leadtime Variability to (s, Q)
  - When transportation leadtime is $N(E[L], \sigma_L)$
    - $E[D_{leadtime}] = E[L]*E[D]$
    - $\sigma_{leadtime} = sqrt(E[L]*\sigma_D^2 + E[D]^2* \sigma_L^2)$
    - then $s = E[D_{leadtime}] + k\sigma_{leadtime}$
  - When transportation leadtime is uniform distribution from $L_1 \sim L_2$, w/ mean E[L]
    - $E[D_{leadtime}] = E[L]*E[D]$
    - $\sigma_{leadtime} = sqrt(E[L]*\sigma_D^2 + E[D]^2* \sigma_L^2)$, where $\sigma_L^2 = (L_2 - L_1)^2/12$
- Total Cost with Transportation
  - TC = CT(transportation) + CH(handling) + CS(storage) + CI(inventory holding)

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- One to One System
  - Total CPI (Cost per item) = $rv(T/2 + L) + C_s(1+n_s)/Q + C_d(d/Q) + C_{vs}$
    - T = shipping frequency = D/Q
    - L = leadtime for transportation (yr)
    - d = distance
    - n_s = # of stops
    - C_s = fixed $/ stop
    - C_d = $/ distance
    - C_{vs} = marginal cost/ item/ stop
- One to Many System
  - Local transportation part
    - $E[d_{local}] \approx k^*\text{sqrt}(nX)$, where
      - X = area
      - k = 0.7124 if n>25 and on Euclidean space (e.g. sky, sea)
      - k = 0.765 if grid (e.g. road)
    - Density $\delta = n/X$
    - Ave $d_{stop} = E[d_{local}]/ n = k/\text{sqrt}(\delta)$
  - Total transportation
    - $E[d_{AllTour}] = 2ld_{LineHaul} + nk/ \text{sqrt}(\delta)$
      - l = # of tours