Post Graduate Diploma in Management – 2020
Covid – 19 Term

Supply Planning and Inventory Management

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Saturday, October 10, 2020

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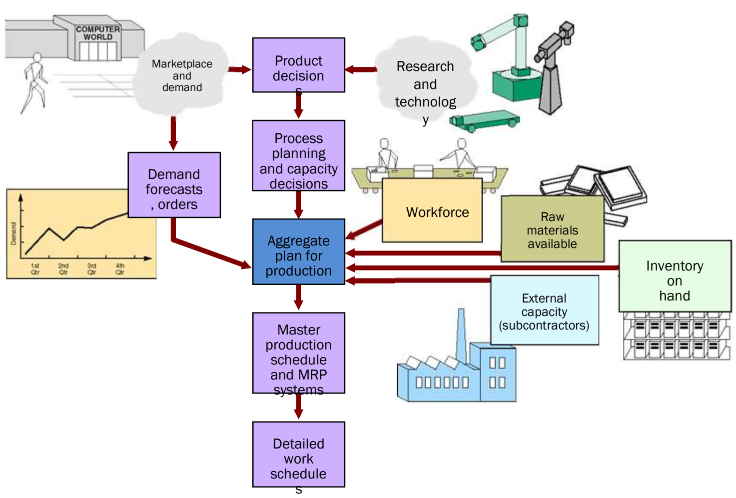

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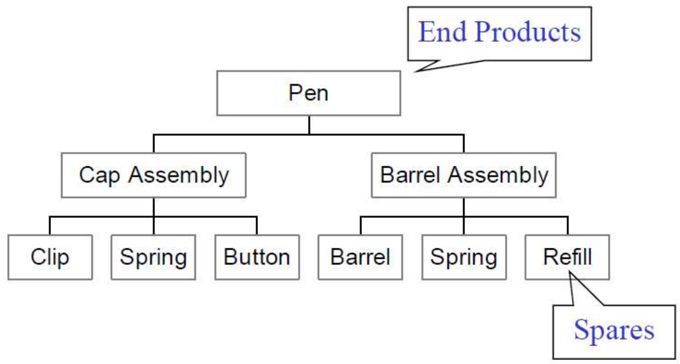
Independent – Dependent Demand



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Why inventories?

- Economies of Scale
- Supply and Demand Uncertainty
- Volume Discounts/Impending Price Rise
- Long Lead Times and Quick Response to Customer's Demand
- To maintain independence of operations
- To allow flexibility in production scheduling

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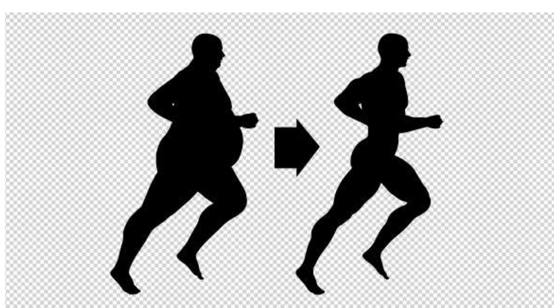
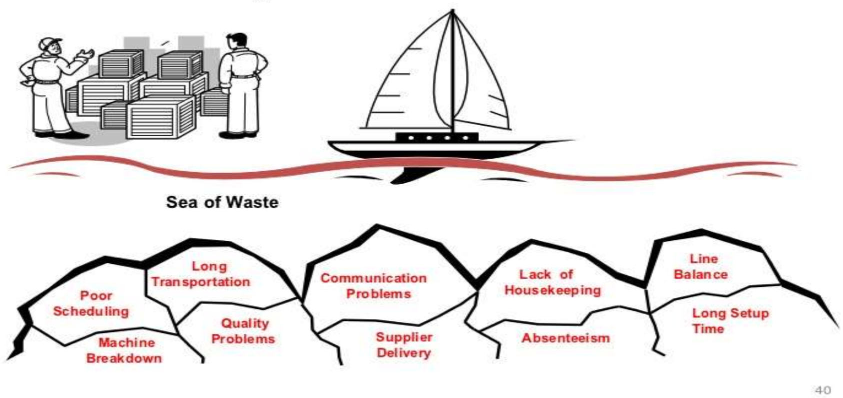
Inventory

Inventory is injurious to your health!



Get Lean...Get healthy!

Inventory Hides Problems



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We want to turn our inventory faster than our people

- A quote by James D. Sinegal
  - Co-founder, Costco

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Inventory Turns

"It was someone from corporate's idea to improve our inventory turns."

$$IT_{sit} = \frac{CGS_{sit}}{\frac{1}{4}\sum_{q=1}^{4} Inv_{sitq}},$$

$$\text{Inventory Turns} = \frac{\text{Cost of Goods Sold}}{\text{Average Inventory}}$$

Should be as high/~~low~~ as possible

INVENTORY TURNS SHOULD ALWAYS BE

Inventory classification

- Classification by form
  - Raw Materials (RM)
  - Work-in-Process (WIP)
  - Finished Goods (FG)
- Classification by Life cycle
  - Perishable
  - Non-perishable

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Inventory classification by function

- Cyclic stock
  - Ordering lot size/2

- Safety stock
  - To protect against uncertainties
- Pipeline
  - Scheduled receipts or open orders

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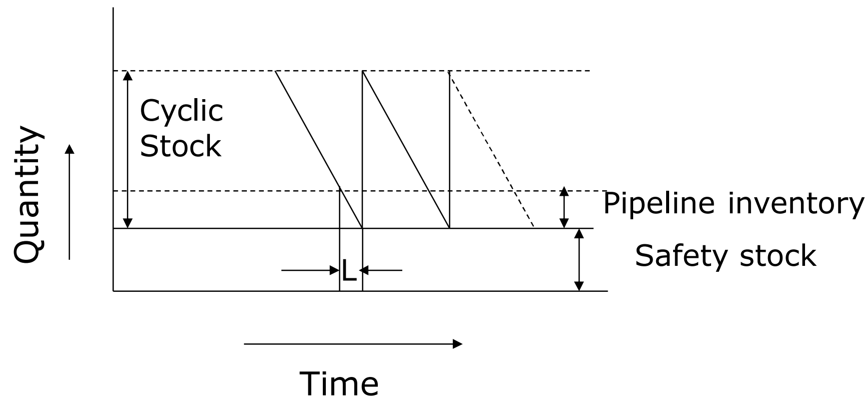
Cyclic, Pipeline and Safety Stocks



Cyclic inventory, pipeline inventory and safety stocks are critically linked to "how much" and "when" decisions in inventory planning

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"I guess smaller, more frequent deliveries are out of the question?"

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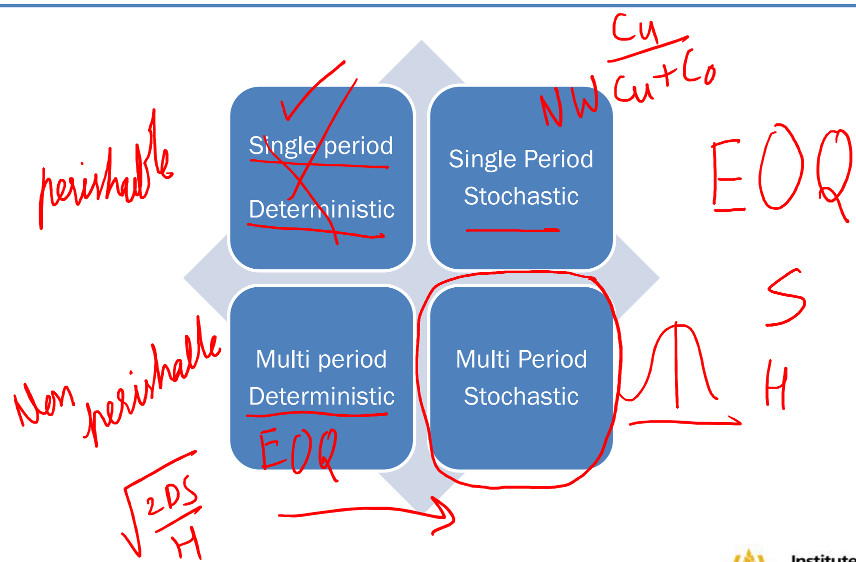
Costs of Inventory

• Physical holding cost (*out-of-pocket*) • Financial holding cost (*opportunity cost*)	• Holding (or carrying) costs
• Production change • Product changeover	• Setup costs
• Low responsiveness – to demand/market changes – to supply/quality changes	• Shortage costs
• Managerial and clerical costs • Transportation costs	• Ordering Costs

Inventory Policy parameters

- WHEN to order?
- HOW MUCH to order?
- In WHAT FORM? *(RM, WIP or FG)*
- WHERE TO DEPLOY in the supply chain?

Types of inventory models



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Single Period Deterministic

- You have to make a decision on how much to inventory in every period
- You know how much the demand for the period is going to be
- What do you do?

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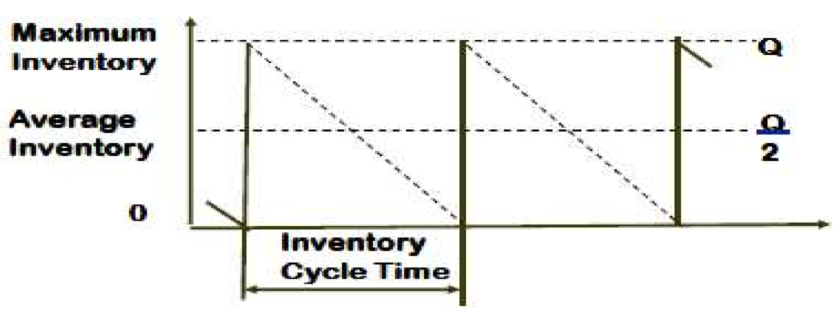
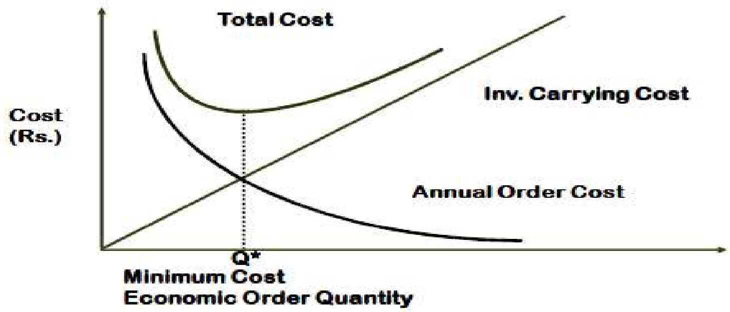
Multi Period Deterministic

- Perpetual inventory system
- Demand for the product is known constant and uniform throughout the period
- Lead time (time from ordering to receipt) is constant
- Replenishment is instantaneous
- Price per unit of product is constant
- Inventory holding cost is based on average inventory
- Ordering or setup costs are constant
- All demands for the product will be satisfied (no back orders are allowed)
- How would the inventory level look like?



- What should be the ordering quantity (Q)?



Tradeoffs: Inventory Carrying versus Annual Ordering Costs

$$TC(Q) = \frac{D}{Q}S + \frac{Q}{2}H$$

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EOQ model

D: Demand per year
S: Setup or Order Cost (Rs/Setup; Rs/Order)
c= unit cost of item
h = Inv holding cost rate
$H=hc$: Inventory holding cost
(Rs./year/unit)
Q: Order quantity
T: Reorder cycle

$$Q^* = \sqrt{\frac{2DS}{H}}$$

$$T = \frac{Q^*}{D} = \sqrt{\frac{2S}{DH}}$$

$$TC(Q^*) = \sqrt{2SDH}$$

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Inventory Planning Models

Mean of weekly demand	: 200
Standard deviation of weekly demand	: 40
Unit cost of the raw material	: Rs. 300/-
Ordering cost	: Rs. 460/- per order
Carrying cost percentage	: 20% per annum
Lead time for procurement	: 2 weeks

EOQ Model

Weekly demand = 200

Number of weeks per year = 52

Annual demand, D = 200*52 = 10,400

Carrying cost, C_c = Rs. 60.00 per unit per year

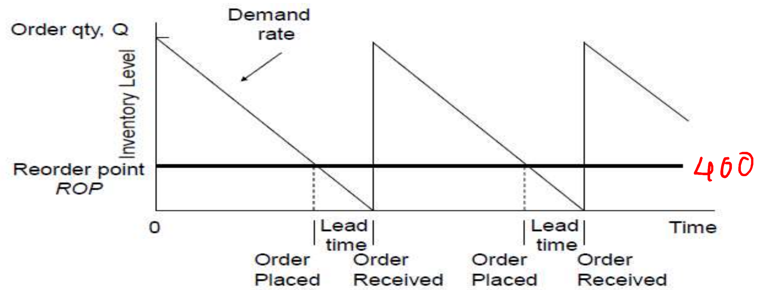
Economic Order Quantity = $\sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 * 460 * 10,400}{60}} = 399.33 \approx 400$

Time between orders = $\frac{400}{10400} = \frac{2}{52} = 2\ weeks$

Practical issues with the EOQ model

- It may not be possible to
  - Order exactly Q*
    - Order as close as possible to Q*
  - Estimate the parameters (D,S,H) accurately
    - EOQ model is robust to small errors in these values
  - Instantaneous replenishment
    - Incorporate lead time using ROP level
  - Price discounts
    - Use modified procedure

Incorporating Lead time



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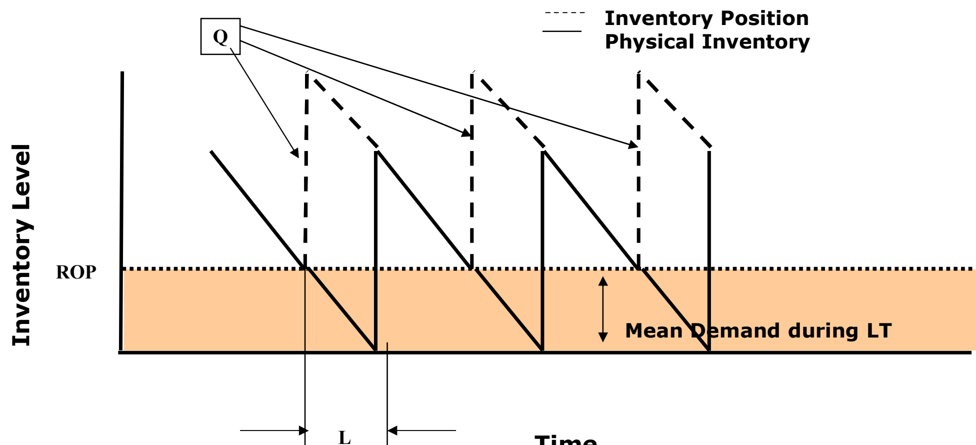
Certain Demand



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Price Discounts

- Why do suppliers give price discounts?
- Compute Q* values
  - From lowest price to the highest
  - Until valid Q* is obtained
- Compute TRC at this Q* and each price break above this Q*
- Choose the order quantity with least TC

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The elephant in the room

Demand uncertainty!!!

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Who's the biggest villain in Operations?

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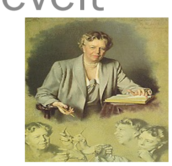
If life were predictable it would cease to be life, and be without flavor.

Eleanor Roosevelt



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Single period Stochastic Demand

- Examples?
  - Newspapers
  - Cakes
  - Fashion products?

Demand characteristics

- Demand follows a normal distribution
  - NORM(50,10)
- How much would you order?

Managing the average will make you an average manager!

A quote by

Understanding Service level

- What area of the demand distribution would you cover?

http://homepage.divms.uiowa.edu/~mbognar/applets/normal.html

Optimal Service level

Happiness is a mysterious thing, to be found somewhere between too little and too much

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Newsvendor model

- Inventory decision under uncertainty
- The “too much/too little problem”:
  - Order too much and inventory is left over at the end of the season
  - Order too little and sales are lost.

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Notation

- Demand D is a random variable
  - Cumulative distribution function F(D)
- Wholesale price W
- Selling price R
- Salvage value S (<W)
- How much should the retailer order?

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"Too much" and "too little" costs

W = 3 R = 12 S = 1

- C_o = overage cost
  - The cost of ordering one more unit than what you would have ordered had you known demand.
  - Increase in profit you would have enjoyed had you ordered one unit lesser.
  - C_o = *Cost – Salvage value* = *W – S* = 2
- C_u = underage cost
  - The cost of ordering one fewer unit than what you would have ordered had you known demand.
  - Increase in profit you would have enjoyed had you ordered one unit more.
  - C_u = *Price – Cost* = *R – W* = 9

$\frac{9}{9+2} = 0.82$

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Balancing the risks and benefits

- Risk : Ordering one more unit increases the chance of overage
  - Expected loss on the Q^{th} unit = C_o x F(Q), where F(Q) = Prob{Demand <= Q)
- Benefit: Ordering one more unit decreases the chance of underage:
  - Expected benefit on the Q^{th} unit = C_u x (1-F(Q))

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Expected profit maximizing order quantity

- To minimize the expected total cost of underage and overage, order *Q* units so that the expected marginal cost with the Q^{th} unit equals the expected marginal benefit with the Q^{th} unit:

$$C_o \times F(Q) = C_u \times (1 - F(Q))$$

- Rearrange terms in the above equation ->

$$F(Q) = \frac{C_u}{C_o + C_u}$$

- The ratio C_u / (C_o + C_u) is called the *critical ratio.*
  - In other terms, *(R-W)/(R-S). R and S are determined by the market.*

R=12 W=3

S=1

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What is the Optimal service level?

Let C_o = Cost of over stocking per unit
C_u = Cost of under stocking per unit
Q = Number of units to be stocked
d = Single period demand
$P(d \leq Q)$ = The probability of the single period demand being at most Q units

$$P(d \leq Q) \leq \frac{C_u}{C_u + C_o} = \text{Service Level}$$

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Multi period Stochastic Demand

- Extending the idea to multiple periods

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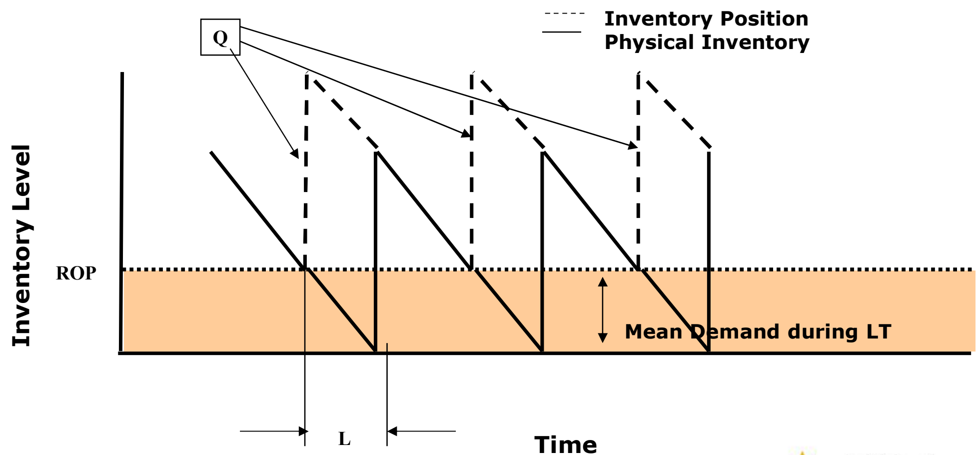
Certain Demand



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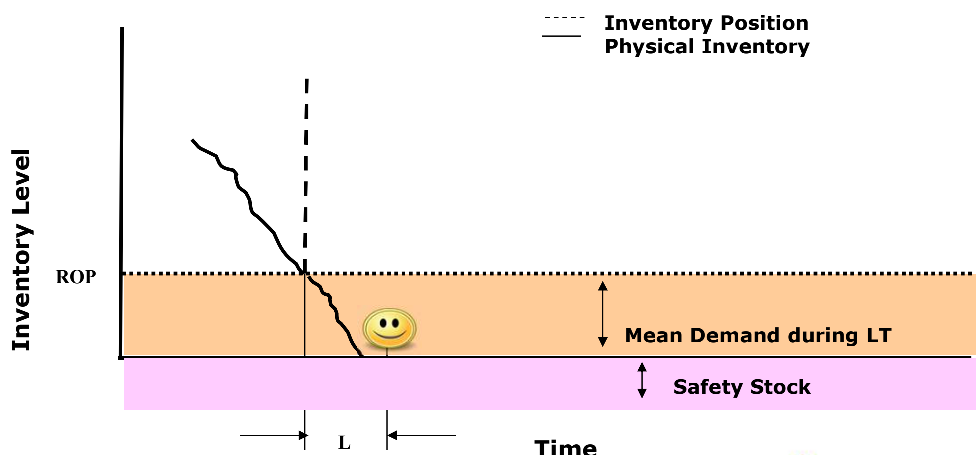
Uncertain Demand



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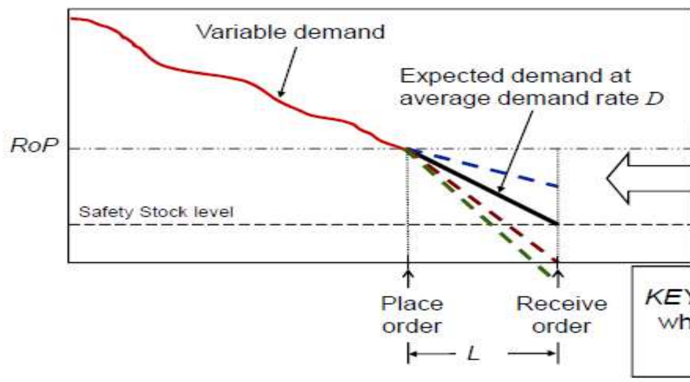
Back to the multi-period setting



QUESTION: How much inventory is needed during lead time *L*?

KEY POINT: RoP is larger when there is uncertainty about demand or *L*

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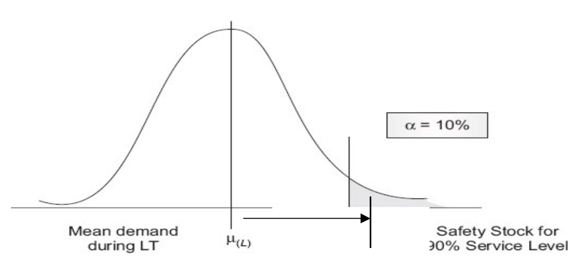
Computing safety stock

Let the demand during lead time follow a Normal distribution
Mean demand during lead-time = $\mu_{(L)}$
Standard deviation of demand during lead-time = $\sigma_{(L)}$
Desired service level = $(1-\alpha)$
The probability of a stock out = α
Standard normal variate corresponding to an area of $(1-\alpha)$ covered on the left side of the normal curve = Z_α



Safety stock (SS) is given by SS = $Z_\alpha * \sigma_{(L)}$

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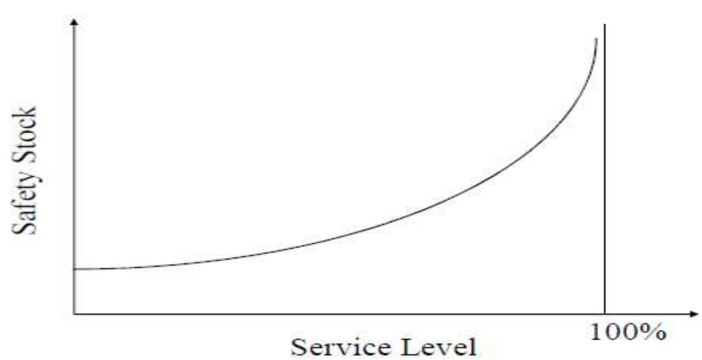
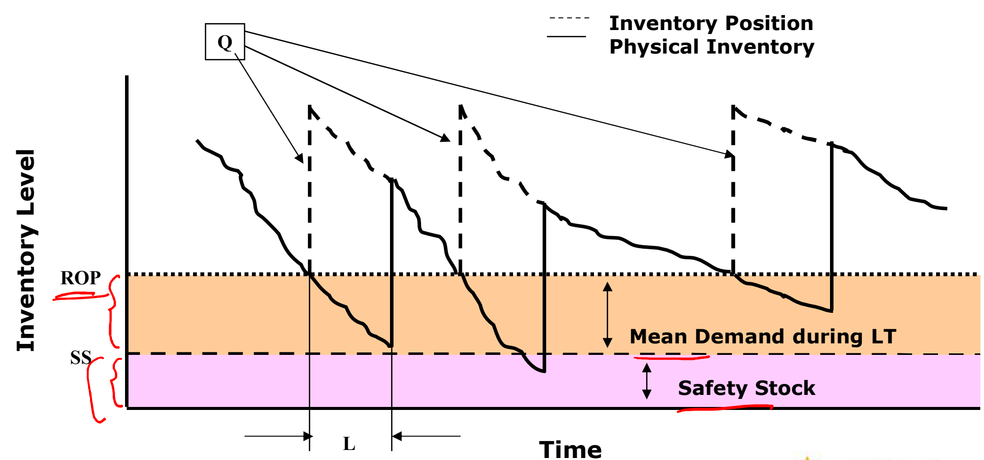
Factors effecting safety stock

- Demand uncertainty (forecast uncertainty)
  - Reducing demand uncertainty (better forecast) reduces safety stock required, reducing material cycle time
- Replenishment lead time
  - Reducing replenishment lead time, improves forecast accuracy, reducing safety stock required (square root factor)
- Variability of supply lead time
  - Reducing variability of supply, improves forecast accuracy, reducing safety stock required

Relationship between Service Level and Safety Stock



Continuous Review (Q) System



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Continuous review policy

L: Lead time
D: Average demand per unit time
σ: Standard deviation of demand per unit time
σ_L :Standard deviation of demand during lead time
ss: Safety stock
k: Safety factor
r: Reorder point
AI: Average inventory
AT: Material Cycle time

$$\sigma_L = \sigma\sqrt{L}$$

$$ss = k \times \sigma_L$$

$$r = D \times L + ss$$

$$AI = \frac{Q}{2} + ss$$

$$AT = \frac{AI}{D}$$

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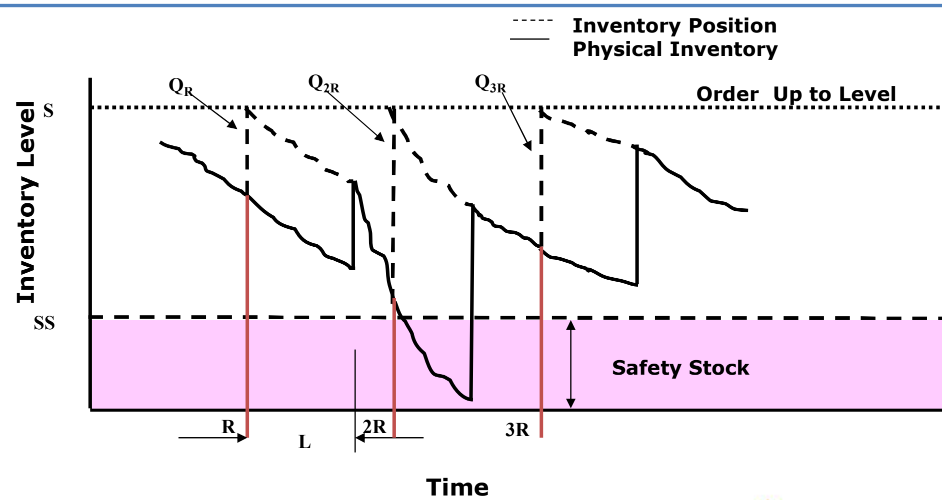
Periodic Review (P) System



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Periodic Review policy

L: Lead time
T: Reorder interval
D: Average demand per unit time
σ: Standard deviation of demand per unit time
σ_{L+T}: Standard deviation of demand during L+T periods
F(k): Cycle service level
ss: Safety stock
k: Safety factor
S: Order up to quantity
AI: Average inventory
AT: Material Cycle time

$$\sigma_{L+R} = \sigma\sqrt{L+T}$$

$$ss = k \times \sigma_{L+T}$$

$$S = D \times (L+T) + ss$$

$$AI = \frac{D \times T}{2} + ss$$

$$AT = \frac{AI}{D}$$

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Periodic & Continuous Review Systems

Criterion	Continuous Review (Q) System	Periodic Review (P) System
How much to order	Fixed order qty: Q	$S = \mu_{(L+R)} + Z_\alpha \times \sigma_{(L+T)}$ $Q_R = S - I_T$
When to order	$ROP = \mu_{(L)} + Z_\alpha \times \sigma_{(L)}$	Every T periods
Safety stock	$SS = Z_\alpha \times \sigma_{(L)}$	$SS = Z_\alpha \times \sigma_{(L+T)}$
Salient aspects	• Implemented using two bin system • Suited for medium and low value items	• More safety stock • More responsive to demand • Ease of implementation

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Hybrid Inventory Policies

- (s,S) policy
  - Optional replenishment system
    - Periodic review with a order upto level
    - Ensures minimum ordering level
    - Eliminates continuous review
- Base stock system
  - Order as much as you sell
  - Base stock level = expected demand during lead time + safety stock
  - Usually orders are accumulated periodically

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