Operations & Supply Planning
PGDM 2018-20

Inventory Management

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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

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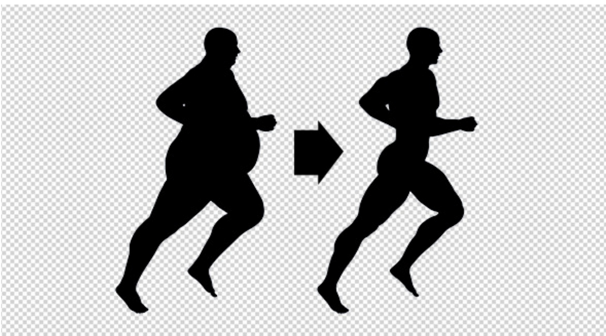
Inventory is injurious to your health!



Get Lean...Get healthy!

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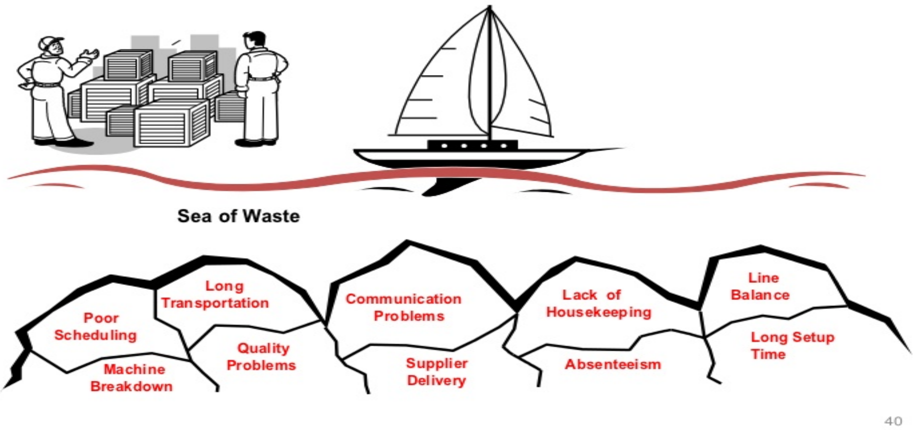
Inventory Hides Problems



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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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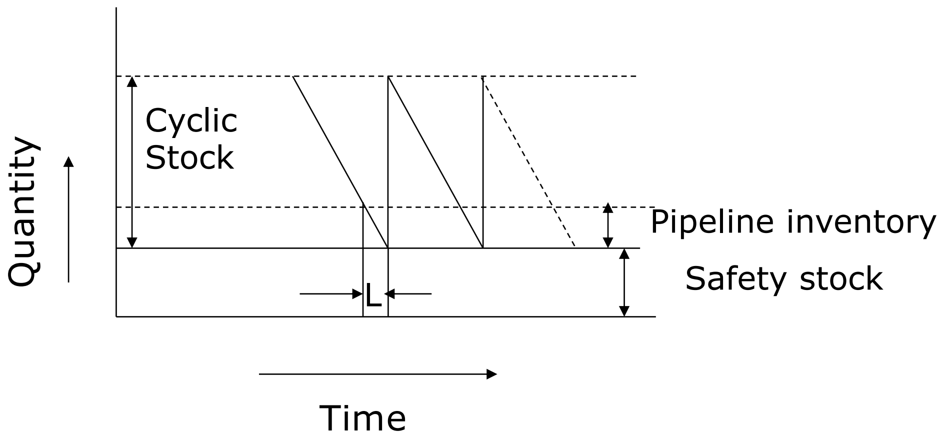
Inventory classification

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

Inventory classification by function

- Cyclic stock
  - Ordering lot size/2
- Safety stock
  - To protect against uncertainties
- Anticipation
  - To absorb uneven rates of demand or supply
- Pipeline
  - Scheduled receipts or open orders

Cyclic, Pipeline and Safety Stocks



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

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

Costs of Inventory

- Physical holding cost (*out-of-pocket*)
- Financial holding cost (*opportunity cost*)
  - Holding (or carrying) costs

- Transportation cost
- Ordering costs
  - Fixed costs

- Low responsiveness
  - to demand/market changes
  - to supply/quality changes
  - Shortage costs

- Obsolescence
  - Inventory writedown

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Inventory Policy parameters

- **WHEN to order?**
- **HOW MUCH to order?**

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

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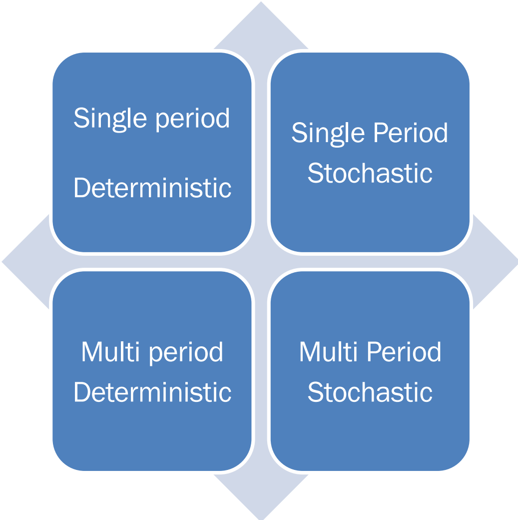
Types of inventory models



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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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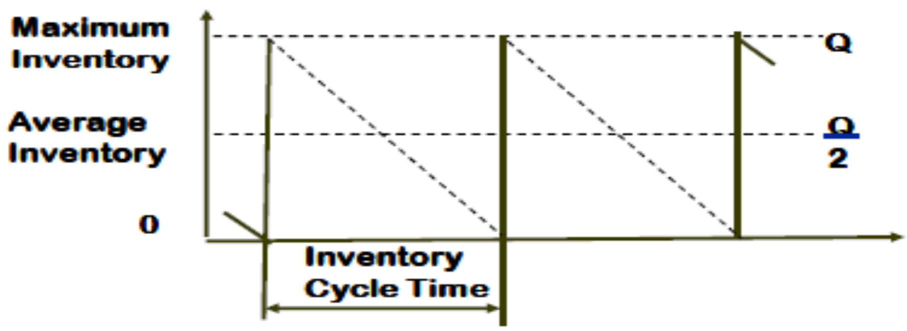
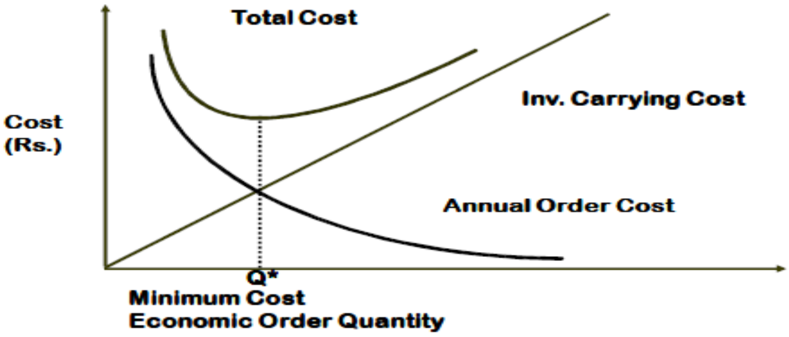
Multi Period Deterministic

- 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 = $\frac{400}{10400} = \frac{2}{52} = 2\,weeks$

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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

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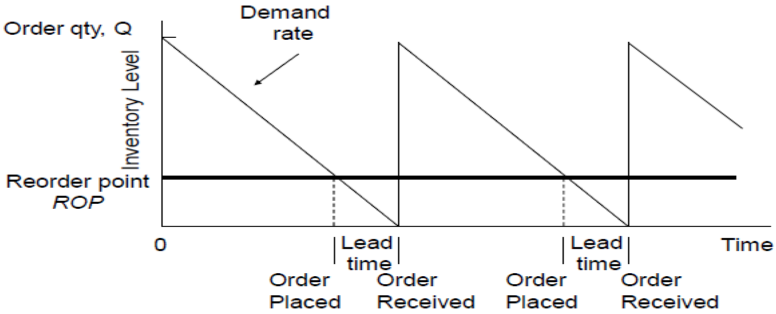
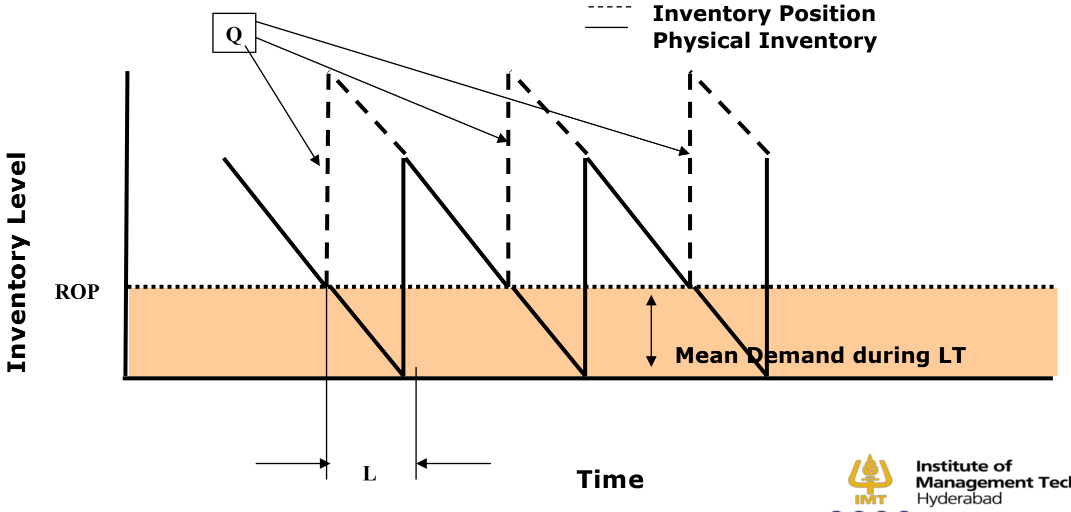
Incorporating Lead time



Certain Demand



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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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?

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Demand characteristics

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

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Managing the average will make you an average manager!

A quote by

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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

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.

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?

"Too much" and "too little" costs

- 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 =*
- 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 =*

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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.*

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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

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

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Multi period Stochastic Demand

- Extending the idea to multiple periods

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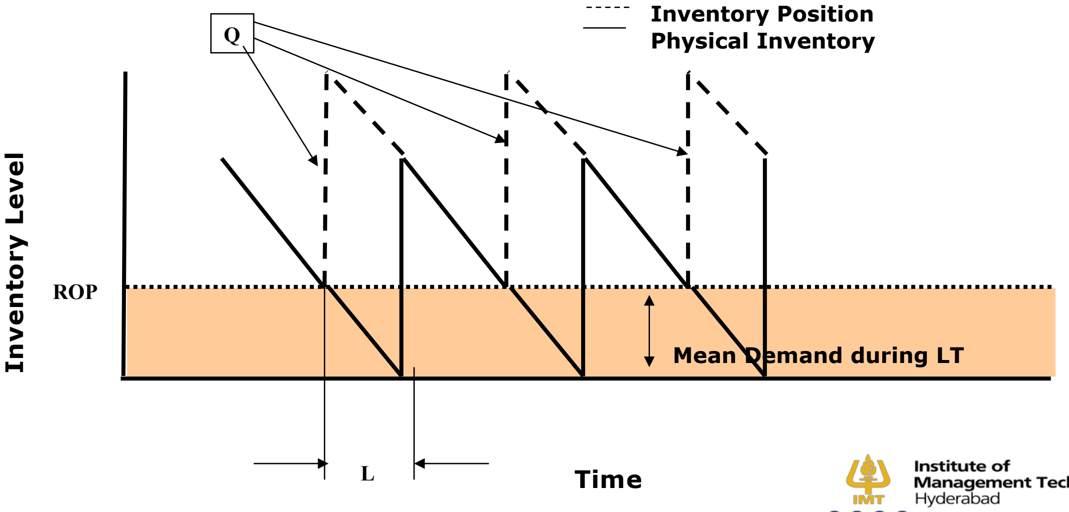
Certain Demand



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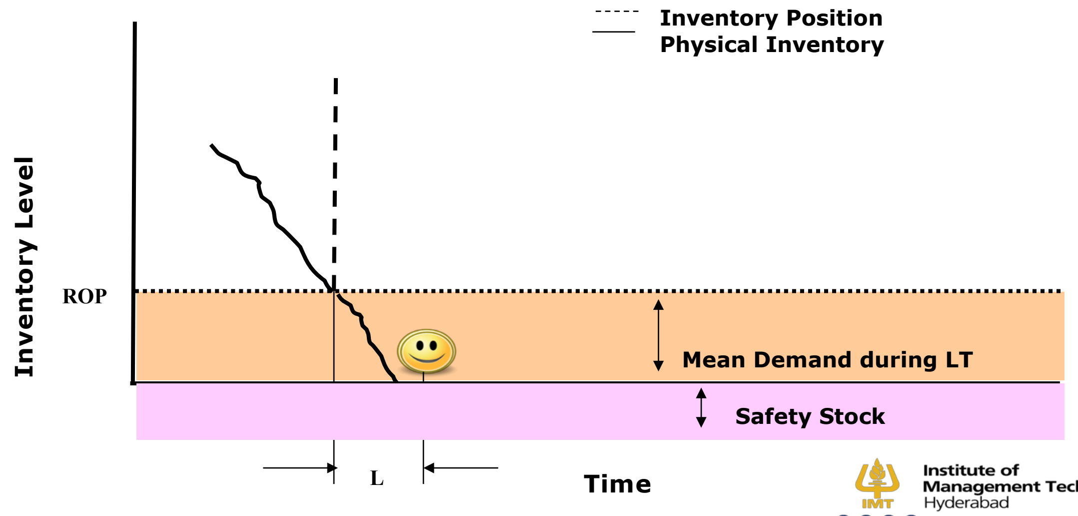
Uncertain Demand



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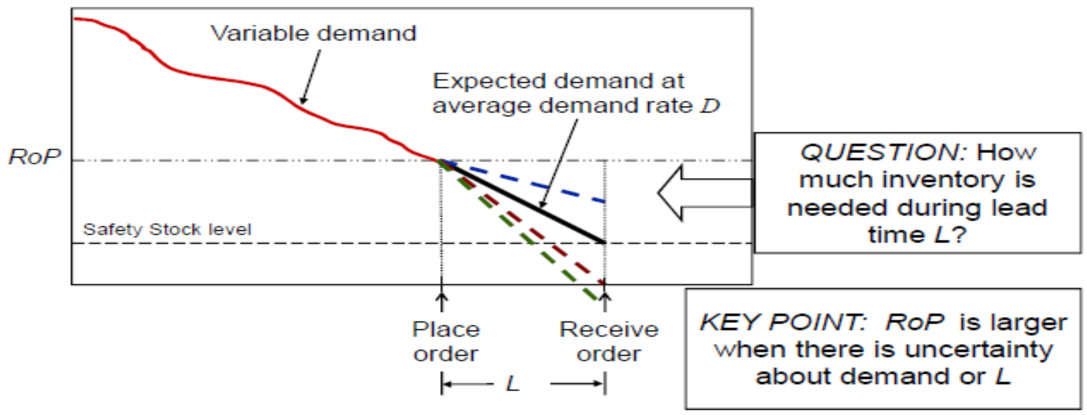
Back to the multi-period setting



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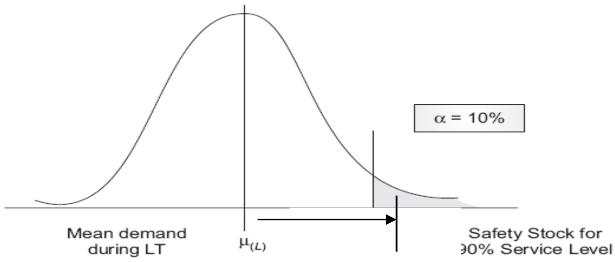
Computing safety stock

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

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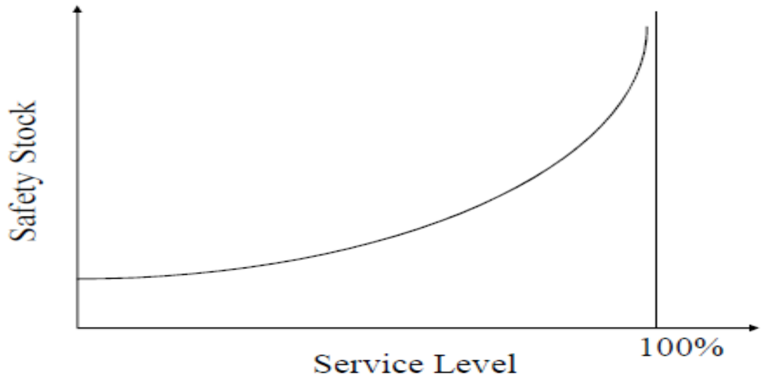
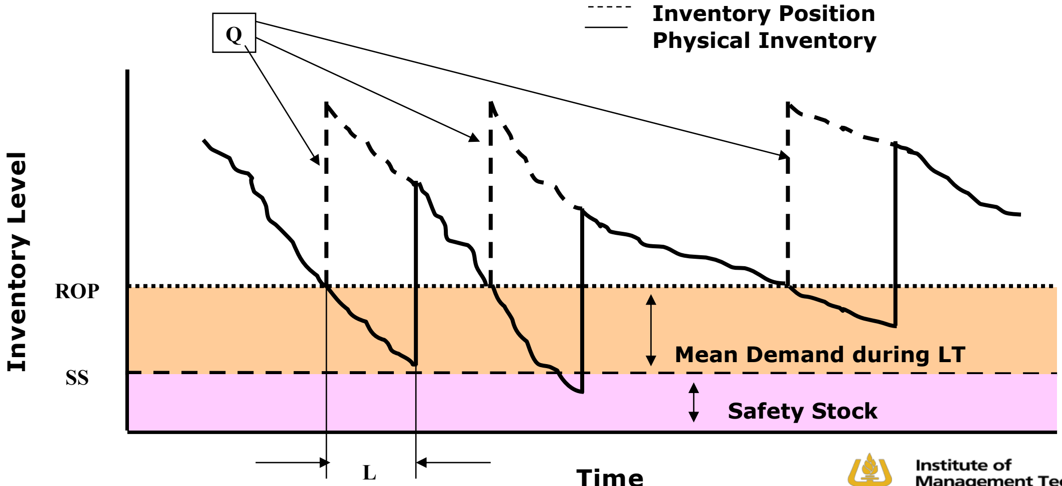
Relationship between Service Level and Safety Stock



Continuous Review (Q) System



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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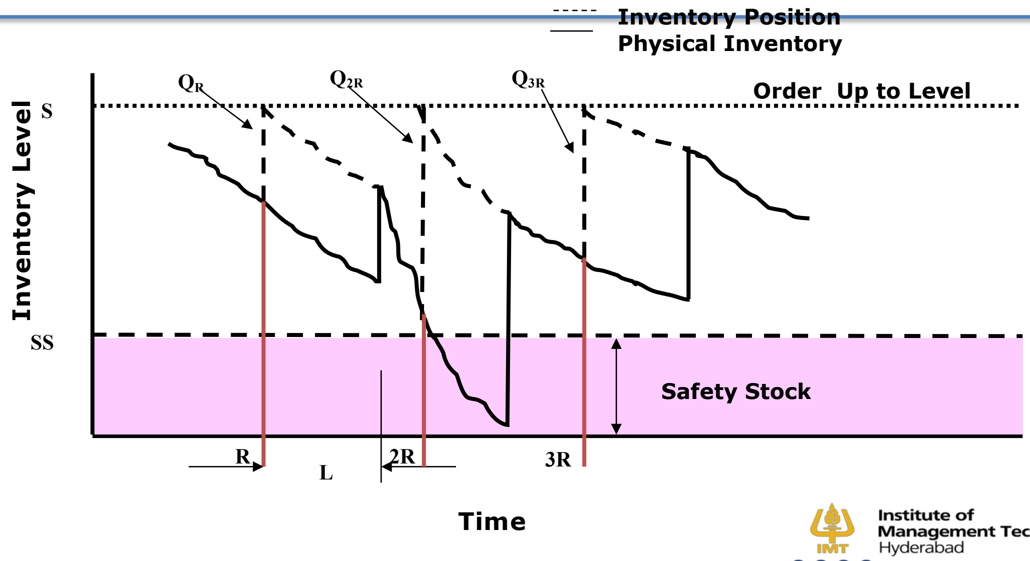
Periodic Review (P) System



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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

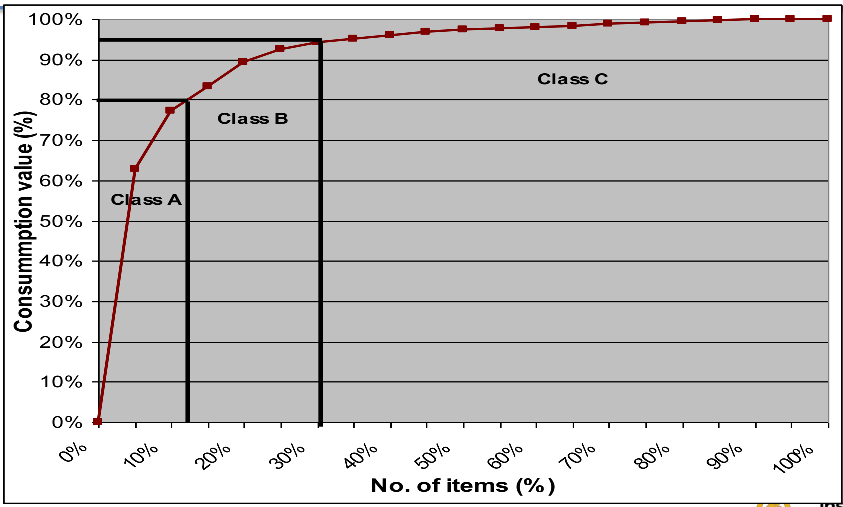
Reducing inventory

Type of inventory	Primary Lever	Secondary Lever
Cyclic	Reduce Q	Reduce ordering and setup cost Increase repeatability
Safety Stock	Place orders closer to the time when the must be received	Improve forecasting Reduce lead time Reduce supply uncertainties Increase equipment and labor buffers
Anticipation	Vary the production rate to follow the demand rate	Level out demand rates
Pipeline	Cut production - distribution lead time	Forward positioning Selection of suppliers and carriers Reduce Q

Selective Control of Inventories

- **ABC Classification (on the basis of consumption value)**
- **XYZ Classification (on the basis of unit cost of the item)**
  - High Unit cost (X Class item)
  - Medium Unit cost (Y Class item)
  - Low unit cost (Z Class item)
- **FSN Classification (on the basis of movement of inventory)**
  - Fast Moving
  - Slow Moving
  - Non-moving
- **VED Classification (on the basis of criticality of items)**
  - Vital
  - Essential
  - Desirable
- **On the basis of sources of supply**
  - Imported
  - Indigenous (National Suppliers)
  - Indigenous (Local Suppliers)

ABC Classification



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Inventory Management in Practice

- Problem of Shrinkage
  - Stock mismatch
- Inventory Management software
- RFID technology
- IoT tech

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THANK YOU

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