ME327 23/02/22

Inventory :-
It is a stock of items kept to meet further demand

Final Product —— Raw Material

Supplier → $\underbrace{\text{Raw material — Inprocess Products — Final Product}}_{\text{Inventory}}$ — Distributor

Types of Inventory :-

1) Raw material and purchased part :- Materials and components required for making a product.

2) Partially completed Goods :- called work in products (WIP)
Materials and components that have begun transformation to finished goods.

3) Finished Goods :- Goods ready for sale to customers i.e items being transported and stored in warehouse.

4) Tools and Equipments

Purpose of inventory

1) To balance against uncertainity
Uncertainity → demand
→ Material delivery.

2) For smooth production
3) To ensure high level customer service.
4) Economics in scale in production or purchasing.
→ Optimum production can lead to minimum cost.
→ Buying in bulk can reduce purchasing cost.

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→ Quantity discount
→ To tackle against price increase.

Two extreme cases :-
→ Large inventory : can increase cost of capital and storage
→ Small inventory : disrupt production and/or sale.
Inventory control deals with optimum size of inventory hence by minimizing appropriate cost.

Inventory policy :-
→ How much to order
→ When to order

Inventory Cost :-
Total inventory cost = Purchasing cost + Holding cost + Ordering cost + Shortage cost.

Purchasing cost : Price per unit of an inventory item. (P×D)
Holding cost : Cost to carry an item in inventory
Holding cost = storage cost + handling cost + depreciation cost + insurance cost + taxes.

Ordering cost : It is fixed when an order is placed.
→ Cost of ordering and receiving inventory.
Shortage Cost : Penalty cost for temporary or permanent loss of sales when demand cannot be made.

Inventory control system
→ Continuous system (fixed order quantity)
* Constant amount ordered when inventory declines to predetermined level.
* Perpetual inventory

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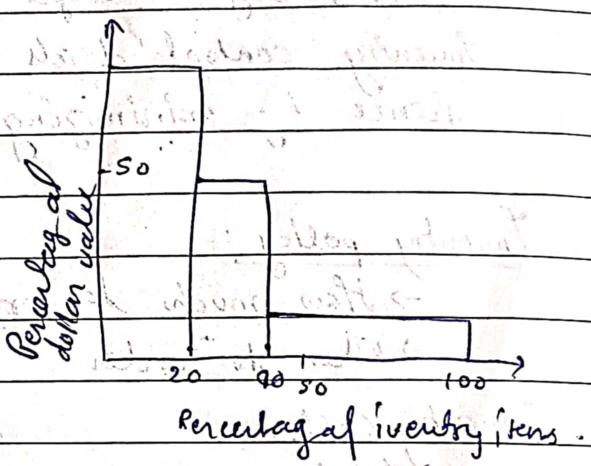
2) Periodic system (fixed time period)

* Orders get placed for variable amount after fixed passage of time
* weekly or daily.

ABC classification System :



class A very important
* 5-15% of units
* 70%-80% of value.

Class B moderate imp.
* 30% of unit.
* 15% of value.

Class C least imp.
* 50-60% of units
* 5-10% of value.

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ABC classification system

classify parts according to ABC classification :

Part	Unit cost $\boxed{P}$	Annual usage $\boxed{D}$	Total cost $\boxed{PD}$
1	60	90	5400 → Annual consumption value.
2	350	40	14000
3	30	130	3900
4	80	60	4800
5	30	100	3000
6	20	180	3600
7	10	170	1700
8	320	50	16000
9	510	60	30600
10	20	120	2400
	Total	1000	85400

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Annual consumption Value

	PD	Q
A	70-80%	5-15%
B	15%	30%
C	5-10%	50-60%

After sorting to descending order of PD.

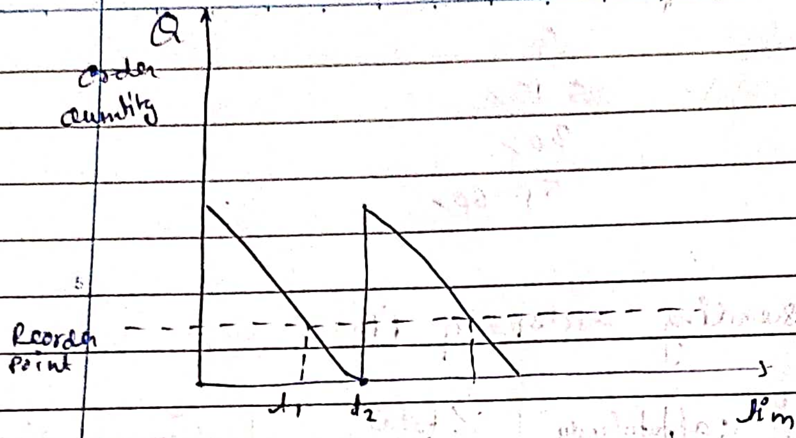
	Part	Total cost (value)	% of total value	% total quantity	Cummulative (Q)
A	9	30600	35.9	6	6
	8	16,000	18.7	5	11
	2	14000	16.4 (71%)	4	15 (15%)
B	1	5400	6.3	9	24
	4	4800	5.6 (16.5)	6 (25%)	30
	3	3900	4.6	10	40
C	6	3600	4.2	18	58
	5	3000	3.5	13	71
	10	2400	2.8 (12.5)	12 (60%)	83
	7	1700	2.0	17	100

Inventory models
Find the order size so that total inventory cost is minimum.

1. Economic order quantity (EOQ) model
2. Economic production Quantity moder (EPQ)

Assumptions for EOQ model.

1) Only one item is involved
2) Annual demand requirement is known (deterministic Model)
3) Demand is even throught the year
4) Lead time does not vary.
5) Each order is received in a single delivery.
6) There is no quantity ~~disc~~ discount.
7) No shortage.



C_0 = cost of ordering.
D = Annual demand
C_h = holding cost / carrying cost. Per unit.
Q = Order Quantity.

1. Annual holding cost (H) = (Avg. no. of inventory) $\times$ (holding cost per unit per year)

$$H = \frac{Q}{2} \times C_h = \frac{QC_h}{2}$$

2. Annual ordering cost = (Cost per order) $\times$ (No. of order per year)

$$= C_0 \times \frac{D}{Q}$$

$$= \frac{C_0 D}{Q}$$

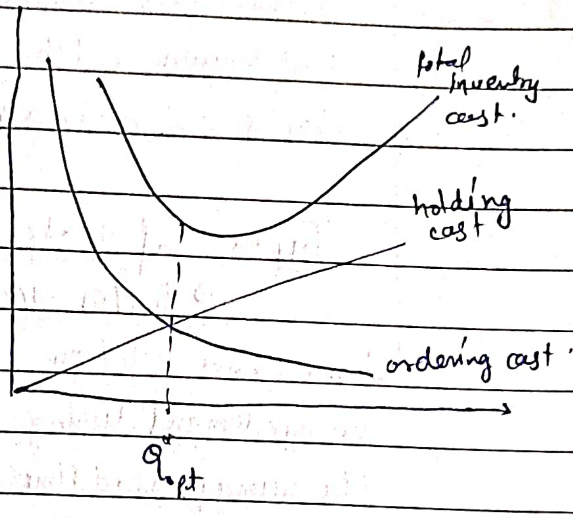
3. Total Inventory cost (TC) $= \frac{QC_h}{2} + \frac{C_0 D}{Q}$

$$\frac{d(TC)}{dQ} = \frac{C_h}{2} - \frac{C_0 D}{Q^2} = 0$$ (Necessary condition for optimality)

$$\Rightarrow Q = \sqrt{\frac{2C_0 D}{C_h}}$$

$$\frac{d^2(TC)}{dQ^2} = +\frac{2C_0 D}{Q^3} > 0 \; ; \text{ at } Q = Q_{opt}$$

It means Q_{opt} will minimize the total inventory cost



Remarks:

1) Optimal length of inventory replenishment cycle time (t^*)

$$t^* = \frac{Q^*}{D}$$

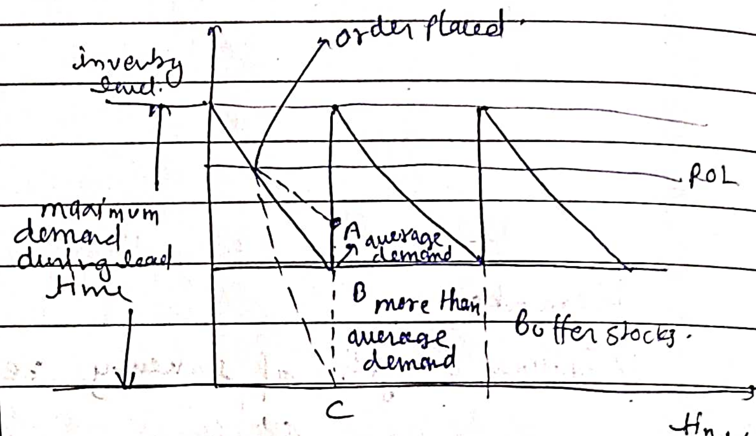
2) Optimum no. of orders $= N^* = \dfrac{D}{Q^*}$

3) If 'r' is the inventory carrying rate and 'C' is the unit cost of the item, $C_h = r \times C$

Additional stocks :-
when the demand rate and/or the lead time are not known with certainity, then additional stocks are maintained.

Types of stocks
→ Buffer stocks

is maintained based on average demand during the average lead time.



(2) Reserve Stock :- is maintained to take care of variation in demand during reorder period.

(3) Saftey Stock :- is maintained to take care of variation in lead time.

Advantages of keeping stocks
→ to maintain stockouts
→ to provide better customer service.

Limitation
→ Increase in total inventory cost.

Buffer stock (BS) = Averagedemand X Average lead time.

exp If demand rate is 100 unit per month and the normal and max. lead time are 10 and 30 days, then

$$BS = \frac{100}{30} \times \left(\frac{10+30}{2}\right) = 66.6 \text{ units}$$

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When no stockouts are desires

$$BS = (\text{Max demand during lead time}) - (\text{Average demand during LT})$$

$$BS = (d_{max} \times LT) - (\bar{d} \times LT) = (d_{max} - \bar{d})\, LT$$

When demand around the average demand $(\bar{d})$ during constant lead time (LT)

$$ROL = \bar{d} \times LT$$

By including buffer stocks (BS)

$$ROL = \bar{d} \times LT + BS$$

Example :-

The annual demand is 12000 units, the ordering cost is Rs 60 /order, the carrying cost is 10% of cost price. The unit cost of the item is Rs 10 and the lead time is 10 days. There are 800 working days in a year. Determine the EOQ and number of order per year. In the past two years the demad rate has gone as high as 70 unit per days. For a reordering system, based on inventry level, what should be the buffer stock? What should be the reordering level at this buffer stock? What would be the carrying cost for a year.

$D = 12000$

$C_o =$ Rs 60 perorder

$C_h = 10\%\ P = 0.1 \times 10 =$ Rs 1 perunit per year.

$P =$ Rs 10

$LT = 10$ days

Working days in a year = 300 days

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(i) $EOQ = \sqrt{\frac{2 C_o D}{C_h}}$

$= \sqrt{\frac{2 \times 60 \times 120000}{1}}$

$= 1200$ units.

(ii) No. of orders =

$= \frac{D}{Q_{opt}} = \frac{120000}{1200} = 10$ order / year.

(iii) $d_{max} = 70$ units/day

Average consumption / demand per day $= \frac{120000}{300} = 40$ units/day.

$BS = (d_{max} - \bar{d}) \times LT$

$= (70 - 40) \times 10$

$= 300$ units.

(iv) Reorder level (ROL) = Avg. demand during LT + bufferstock.

$\Rightarrow \bar{d} \times LT + 300$

$\Rightarrow 40 \times 10 + 300$

$\Rightarrow 700$ units

(v) Average Inventory level $= BS + \frac{Q^*}{2}$

$= 300 + \frac{1200}{2}$

$= 900$ units

Annual carrying / holding cost $= 900 \times C_h$

$= 900$

Continuous system (Q system) with uncertain demand.

- If the demand during lead time is varying unexpectedly in a ~~very the~~ way that the amount of buffer stock is not

enough to meet it, then there would be stock out.
It can be avoided by
1) Increasing buffer stocks, meaning increasing the average inventory $(BS + \frac{Q^*}{2})$.
2) Raising level of ROL above average demand and ~~adjustment~~ adjusting order quantity (Q^*)

In Q-system, the probability of variation in demand during lead time (DDLT) is controlled by raising or lowering ROL

Step I : Calculate Q^* (EOQ) $= \sqrt{\frac{2C_0 D}{C_h}}$

II Determine ROL to trade-off b/w shortage cost and carrying cost for creating additional inventory (also called reserve stock). This reserve stock is the number of unit by which ROL is raised above expected (average) demand during lead time to balance shortage cost.

If DDLT is probabilistic and normally distributed, then
ROL = average demand during average lead time + Reserve stock + Safety stock.

Reserve stock (RS) = Service level factor X Standard deviation demand during lead time.

Safety stock (SS) = Average demand during maximum delaying lead time x Probability of such delay.

Imp DDLT usually is described by a probability density function per unit time (eg. per day)

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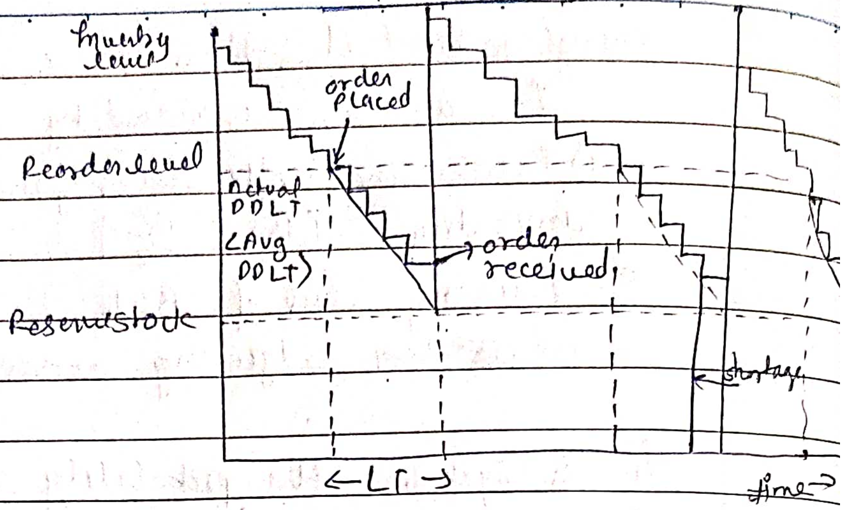


Assumptions :- During DDLT

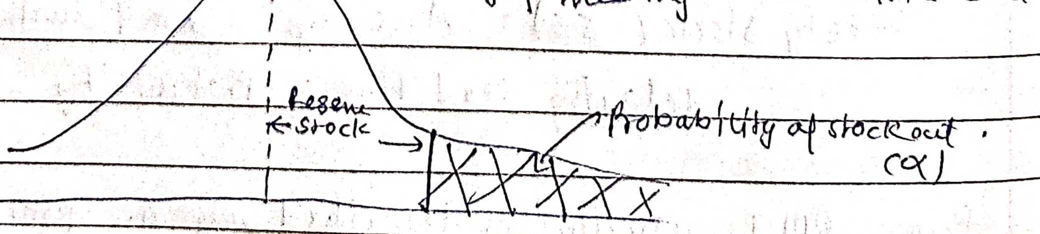
1) $\bar{D}$: Average demand during lead time (LT)
σ_D : Standard deviation described by normal probability distribution.

2) Demand in one period is independent of another periods.
n : number of periods in the lead time.
$\bar{d}$: average demand for items per unit time (periods)
Z : number of standard deviations from average of DDLT distribution required for a specific service level.
σ_d^2 : variance of demand for items per unit time.

$$(\sigma_D)^2 = h_1 \sigma_d^2 + h_2 \sigma_d^2 + \cdots h_n \sigma_d^2$$
$$= \sum h_i \sigma_d^2 = \sigma_d^2 (LT)$$
$$\Rightarrow \sigma_D = \sigma_d \sqrt{LT}$$

Reserve Stock $= Z\sigma_D = Z\sigma_d \sqrt{LT}$

$ROL = \bar{d} \times LT + Z\sigma_D = \bar{d} \times LT + Z\sigma_d \sqrt{LT}$



$M_{LT} = \bar{d} \times LT$

Service level $(1-\alpha)$	Z
80%	0.84
90%	1.28
99%	2.32

$$ROL = \bar{d} \times LT + Z\sigma_D$$

$$\Rightarrow Z = \frac{ROL - \bar{d} \times LT}{\sigma_D}$$

(Q) The following have been collected for an item:
Annual demand (D) = 1800 units, ordering cost Rs 100 / order, cost of item is Rs 5 / unit ; carrying cost is 20% of unit cost per year per item, Replenishment lead time is 2 days, mean demand during replenishment time is 100 units with standard deviation of 30 units and normally distributed. The stockout probability during lead time is 25%. When and how much to order for Q-system?

Given $D = 1800$ $\quad$ $P = Rs\ 5/unit$

$C_o = 100$ $\quad$ $C_h = 20\%$ of P = 1 per unit per year

$LT = 2$ days, $\bar{d} = 100$, $\sigma_d = 30$

$Z(75\%) = 0.67$

(a) $$Q^* = \sqrt{\frac{2C_oD}{C_h}} = \sqrt{\frac{2 \times 100 \times 1800}{1}} = 600.$$

(b) When to order:

$$ROL = \bar{d} \times LT + Z\,\sigma_d\sqrt{LT}$$

$$= 100 \times 2 + 0.67 \times 30 \times \sqrt{2} = 229 \text{ approx.}$$

when an effective inventory drops to 229 units, place an order of 600 units.

(2) A manufacturing company requires a component at the annual average rate of 1000 units. Placing an order cost Rs 480 and has a 5 day lead time ~~Inventory~~ Inventory holding cost is estimated as Rs 15 per unit per year. The plant operates ~~on~~ 250 days per year. It is assumed that daily demand is normally distributed with an average of 4 units with a standard deviation of 1.2. Suggest an inventory policy to control inventory of the item based on a 95% service level.

$D = 1000$, $C_o = Rs\ 480$, $LT = 5$ days

$C_h = Rs\ 15$ per unit per year.

DDLT: $\bar{d} = 4$, $\sigma_d = 1.2$

Service level $(1-\alpha) = 95\%$, $z(95\%) = 1.65$

$ROL = \bar{d} \times LT + z\,\sigma_d \sqrt{LT}$

$= 4 \times 5 + 1.65 \times 1.2 \times \sqrt{5}$

$= 25$ units approx.

Inventory policy is to keep

(Reserve stock) $RS = ROL - \bar{d} \times LT = 25 - 20 = 5$ units and place an order when effective inventory drops to 25 units.

Forecasting

1) Forecasting is a prediction of what will occur in the future
2) The process of analyzing current and historical data to determine future trends.
3) Forecasting is an art of specifying meaningful information about future.

Examples:-

→ Meterologists forecast the weather
→ Gamblers predict the winner of a football game
→ Manager of business firms attempt to predict how much of their product will be desired in the future.

A forecast of product demand is the basis for most important management planning decisions.
→ Scheduling, inventory control, process control, facility layout, workforce, material purchasing etc.

Characteristics of forecast:-

→ A good forecast gives some measure of error.
→ Forecasting technique should be used with known information
→ Forecasting aggregate units is easier than for individual units.

Forecasting horizons

Short Range forecast

→ time frame from one day to three months
→ Used for day to day production :- Scheduling, inventory planning, workforce planning etc.

Medium Range forecast.

→ Time frame from 3 months to 3 years.
→ Used for production and layout planning, sales and marketing planning, capital budget planning etc

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Long Range forecast

- Time frame more than three years
- used for strategic planning in terms of capacity planning, new product planning, expansion planning etc.

Forecasting Methods :-

1. Qualitative methods
   - based on human judgement
   - If historically data is not available.
   - Used for long range forecasting.

2. Casual forecasting method
   - uses some explanatory variables to predict the future
   -

3. Time series methods / analysis
   - Statical techniques based on historical data

Assumption :- past trend will continue in future.

Qualitative methods :-

1. Sales force composites
   → Salesforce or customer service area has direct contact with consumers
   → They are in good position to see changes in market
   → Sales managers can predict demand.

2. Customer survey or market survey
   - organised approach using surveys to determine customer needs and wants for the products / services
   - It can provide quite accurate and useful forecast
   - Needs skill, should be conducted accurately
   - It can be expensive
   → Conducted through mailing, telephones or personal interviews

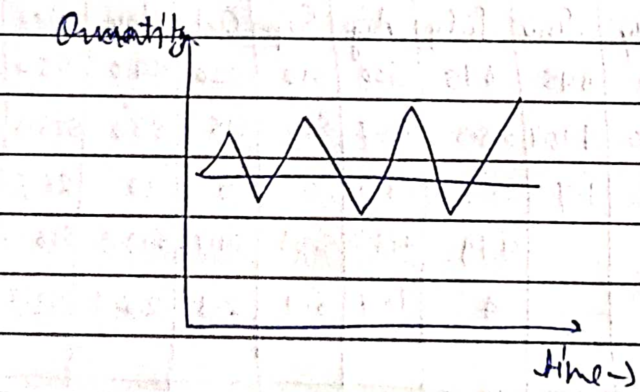
- Needs sufficient responses for forecast
- Design of questionnaires, number of responses and sampling ~~satisfying~~ plans or scheme should be accurate

③ The Delphi method

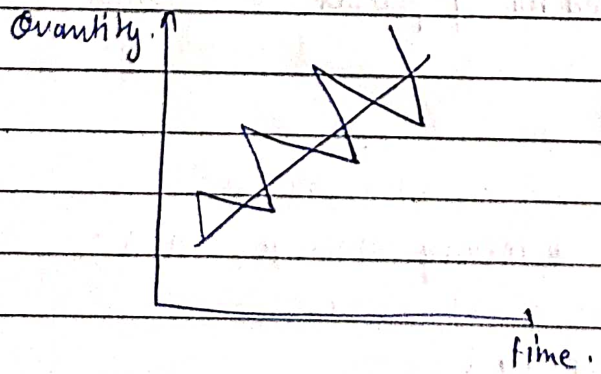
→ Useful for forecasting for technological change and advances.
→ Expert opinions are collected for preparing forecast.

~~Time~~

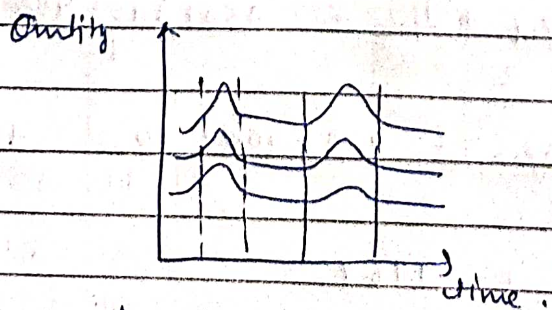
Demand behavior



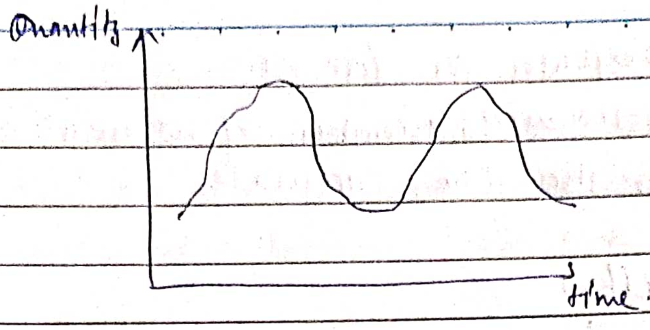
Horizontal pattern/ historical pattern/ stationary pattern.



Trend pattern: Gradual long term up or down movement



Seasonal pattern: short term.
regular variation in data



cyclic pattern :

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Forecasting methods

Months	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan
Demand	450	490	460	510	520	495	475	560	510	520	540	550	
1- 3months moving average	–	–	–	450	470	496.7	508.3	496.7	510	515	530	523.3	536.7
mean absolute error				60	50	1.7	33.3	63.3	0	5	10	26.7	27.8
6 month moving average.	–	–	–	–	–	–	479.	483.33	503.3	511.7	513.3	516.7	525.8
mean absolute error.							4	76.7	6.7	8.3	26.7	33.3	26

Simple moving average :

Average data for desired no. of periods

$$F_t = \frac{\sum_{i=1}^{n} D_{t-j}}{n}$$

For example, 3 month moving average, n=3.

$$F_t = \frac{D_{t-1} + D_{t-2} + D_{t-3}}{3}$$

$$F_{april} = \frac{D_{march} + D_{fed} + D_{jan}}{3} = \frac{450+490+460}{3} = 450$$

$$F_{may} = \frac{D_{april} + D_{march} + D_{feb}}{3} = \frac{490+460+510}{3} = 470$$

$$F_{june} = \frac{460+510+520}{3} = 496.7$$

Forecasting performance error

(i) Mean absolute error / deviation, $MAD = \frac{\sum |\text{Actual demand} - \text{forecasted value}|}{n}$

→ measures the total error.

(ii) Cummulative forecast error (CFE)

$$CFE = \sum (\text{Actual demand} - \text{forecasted demand})$$

→ It measures any bias in the forecast

(iii) Mean square error (MSE)

$$MSE = \frac{\sum (\text{Actual demand} - \text{forecasted demand})^2}{n}$$

→ Penalize large error.

MAD for 3 months average.

$MAD_{April} = |510 - 450| = 60$

$MAD_{may} = |520 - 470| = 50$

$$F_{July} = \frac{D_{Jan} + D_{Feb} + D_{March} + D_{April} + D_{May} + D_{June}}{6}$$ {for 6 month}

$$F_{July} = \frac{450 + 440 + 460 + 510 + 520 + 495}{6}$$

$F_{July} = 479$

Months.	Jan	Feb	Mar	April	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan
3 month weighted moving average				452.6	480	502.5	505	491.3	522.5	513.8	527.5	527.5	540
mean absolute error				57.5	40	7.5	30	68.75	12.5	6.25	12.5	22.5	28.6
exponential smoothing		450	442	457.6	498.1	508.5	490.8	475.6	543.6	506.8	515.4	532.3	541.9
Mean absolute error.		10	18	52.4	21.9	13.5	15.8	84.4	33.5	13.2	24.6	17.7	25.4
double exp. smoothing.	450	457.3	460.8										549.8
Trend (T_t)	9.1	8.7	7.7										8.2
MAD	0	17.3	0.8										

weighted moving average :-

- higher weight is assigned to most recent dates.

$$F_t = \sum_{j=1}^{n} w_j D_j \quad , \text{where } \sum_{j=1}^{n} w_j = 1$$

example

$F_{april} = 0.5\, D_{march} + 0.25\, D_{feb} + 0.25\, D_{Jan}$

$= 0.5 \times 460 + 0.25 \times 440 + 0.25 \times 450$

$= 452.6$

$MAD_{april} = 510 - 452.6$

$= 57.5$

$F_{may} = 480$

$MAD_{may} = 40$

Exponential smoothing :-

$$F_{t+1} = \alpha D_t + (1-\alpha) F_t$$

α = smoothing constant, $0 \le \alpha \le 1$

- most frequently used in time series method because it is simple to use and ~~without~~ minimal amount of data needed i.e. F_t, D_t, α.

$\Rightarrow F_1 = D_1$

$\alpha = 0.8$ {for this case}.

$F_{feb} = \alpha D_{Jan} + (1-\alpha) F_{Jan}$

$= 0.8 \times 450 + (1-0.8)\, 450$

$= 450$

$F_{march} = \alpha D_{feb} + (1-\alpha) F_{feb}$

$= 0.8 \times 440 + (1-0.8)\, 450$

$= 442$

Double exponential smoothing or Holt trend

$$F_{t+1} = \alpha D_t + (1-\alpha)(F_t + T_t)$$

$$T_t = \beta(F_t - F_{t-1}) + (1-\beta)T_{t-1} \quad ; \quad 0 \leq \beta \leq 1$$

T_t : Trend.

Initial values:

1) $F_1 = D_1$

2) $T_1 = (D_2 - D_1)$ method 1

$T_1 = [(D_2 - D_1) + (D_3 - D_2) + (D_4 - D_3)]/3$

$T_1 = (D_4 - D_1)/3$

$$T_1 = \cancel{\frac{D_4 - D_1}{n}} \quad \frac{D_n - D_1}{(n-1)}$$

exp: $\alpha = 0.2$, $\beta = 0.2$

$F_1 = D_1$

$$T_1 = \frac{D_{dec} - D_{Jan}}{11} = \frac{550 - 450}{11} = 9.1 = T_{Jan}$$

$F_2 = 0.2 \times D_{Jan} + (1-0.2)(F_{Jan} + T_{Jan})$

$F_2 = 0.2 \times 450 + 0.8(450 + 9.1)$

$F_2 = 457.3$

$T_2 = 0.2(457.3 - 450) + 0.8(9.1) = 8.7$

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Trend projection by linear regression

$Y = a + bx$

x = time

Y = Forecasted value / demand

$$b = \frac{\Sigma xy - n\bar{x}\bar{Y}}{\Sigma x^2 - n\bar{x}^2}$$

$$a = \bar{Y} - b\bar{x}$$

exp

Weeks (X)	Sales (Y)	XY	X*X
1	150	150	1
2	157	314	4
3	162	486	9
4	166	664	16
5	177	885	25
6			

~~15/5~~

$\bar{X} = \frac{15}{5} = 3$

$\bar{Y} = 162.4$

$\Sigma XY = 2499$

$\Sigma X^2 = 55$

$n = 5$

$$b = \frac{2499 - 5 \times 3 \times 162.4}{55 - 5 \times (3)^2}$$

$b = 6.3$

$a = \bar{Y} - b\bar{X}$

$a = 162.4 - 6.3 \times 3$

$a = 143.5$

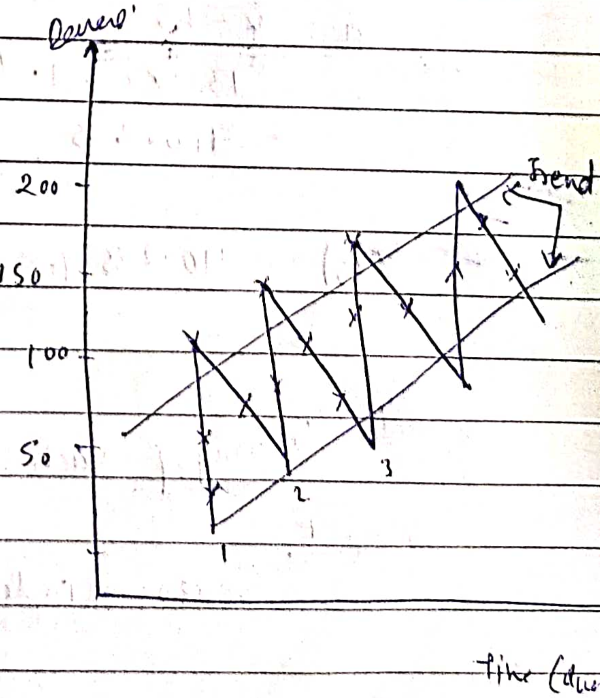
$Y(c) = a + bx = 143.5 + 6.3 \times 6$

$= 181.3$

Forecasting seasonality.

Year	1				2				3				4			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Demand	72	110	172	117	76	112	194	130	78	119	201	128	281	139	216	141
Seasonal index																
Forecast.																

Year	5			
Quarter	1	2	3	4
Demand	199.875			
Seasonal index	0.5901	0.913	1.505	0.9918
Forecast.	88.99	136.83	222.55	198.65



Step 1

Divide the data seasonwise.

Step 2

linear regression for trend.

Year (X)	Avg (Y)	XY	X^2
1	117.75	117.5	1
2	128	256	4
3	131.5	394.5	9
4	143	572	16

$\bar{X} = 2.5$, $Y = 130.06$, $\Sigma XY = 1390.25$

$$b = \frac{1390.25 - 4 \times 2.5 \times 130.60}{30 - 4(2.5)^2}$$

$= 7.93$

$a = \bar{Y} - b\bar{X}$

$= 130.60 - 7.93 \times 2.5$

$= 110.235$

$Y(5) = 110.235 + 5 \times 7.93 = 149.875$

Step 3

Average of each season

Step 4

$$\text{Seasonal index} = \frac{\text{Average of each season}}{\text{total average.}}$$

Quiz (2) 27th April, 4-5 pm. (Sec-B).
After midsem.

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Quarter \ Year	1	2	3	4	Avg	Seasonal index
1	72	76	78	81	76.75	
2	110	112	119	134	118.75	
3	172	194	201	216	195.75	
4	117	130	128	141	129	
Average	117.75	128	131.5	143	130.06	

Seasonal Index for quarter 1 $(SE_1) = \frac{76.75}{130.06} = 0.5901$

$SE_2 = \frac{118.75}{130.068} = 0.9130$

Step-5 Forecast for the 5th Year.

$Q_1 = 149.875 \times SE_1 = 149.875 \times 0.5901 = 88.44$

$Q_2 = 149.875 \times SE_2$

$Q_3 = 149.875 \times SE_3$

$Q_4 = 149.875 \times SE_4$

20/04/2022

Operation scheduling.

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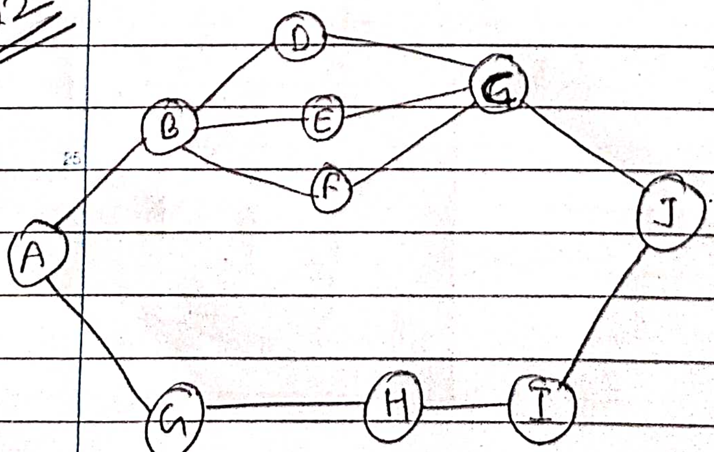
Elemental work	Time	Immediate Predecessor
C	50	A
A	40	None
D	40	B
B	30	A
F	25	C
H	20	D,E
I	18	F, G
G	15	C
E	6	B

Elemental work	Time	Immediate predecessor
C	50	A
A	40	None
D	40	B
B	30	A
F	25	C
H	20	D, E
I	18	F, G
G	15	C
E	6	B

Workstation	Elemental work	Work station time	Cycle time (sec)	Idle time (sec)
1	A	40	60	20
2	C	50	60	10
3	B, F	30+25	60	5
4	D, G	40+15	60	5
5	I, E H	18+6+20	60	16

Ex2



Element work	Time	Immediate Predecessor	Workstation	Element work	Workstation time	Cycle time	Idle time
H	145	G	1	A, B, D	40+80+25	150	5
I	130	H	2	G, E	120+20	150	10
G	120	A	3	H	145	150	5
J	115	G, I	4	I, F	130+15	150	5
B	80	A	5	C, J	145	150	5
A	40	None					
C	30	D, E, F					
D	25	B					
E	20	B					
F	15	B					

$\frac{1}{192}$ $\quad \frac{1}{24} = \frac{3600}{24} = 150$ sec/unit.

Theoretical min no. of workstation $= \frac{720}{150} = 5$