Smt. S R Patel Engineering College, Dabhi

<u>Cover page of Lecture Notes</u>

Faculty Name: **Asst. Prof. Harshad C Patel**

Branch: **ME** Semester: **7th**

Name of Subject: **CIM**

Chapter/ Unit No.

CAPP

7

CAPP

Prepared By
H. C. Patel

न हि ज्ञानेन सदृशं पवित्रमिह विद्यते।
Smt. S. R. PATEL ENGINEERING COLLEGE

Forecasting is essential for a number of planning decisions

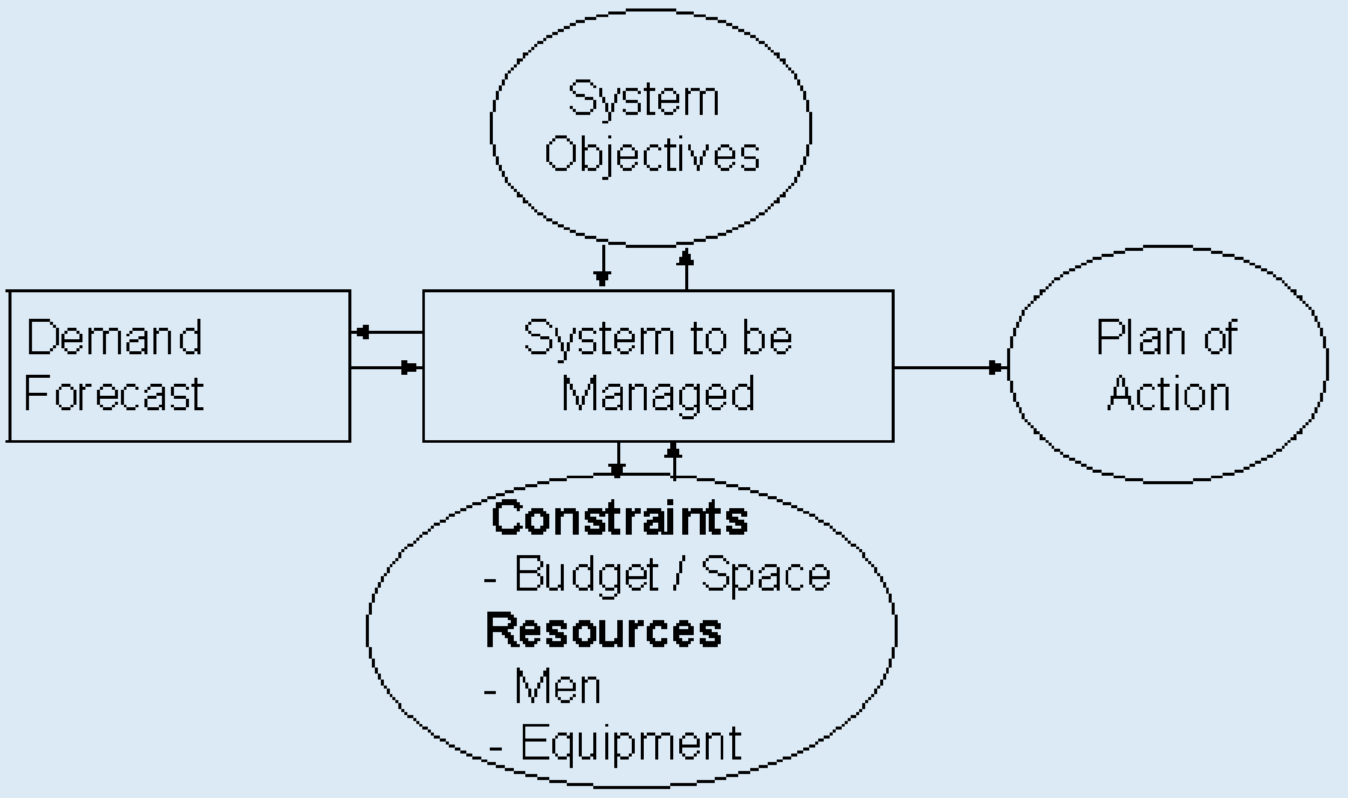
LONG TERM DECISIONS
- New Product Introduction
- Plant Expansion

MEDIUM TERM DECISIONS
- Aggregate Production Planning
- Manpower Planning
- Inventory Policy

SHORT TERM DECISIONS
- Production planning
- Scheduling of job orders

PLANNING PROCESS

- A Forecast of Demand is an essential Input for Planning



METHODS OF FORECASTING

- (a) Subjective or intuitive methods
  - Opinion polls, interviews
  - Brainstorming
  - DELPHI

  (b) Methods based on averaging of past data
  - Moving averages
  - Exponential Smoothing

METHODS OF FORECASTING

(c) Regression models on historical data

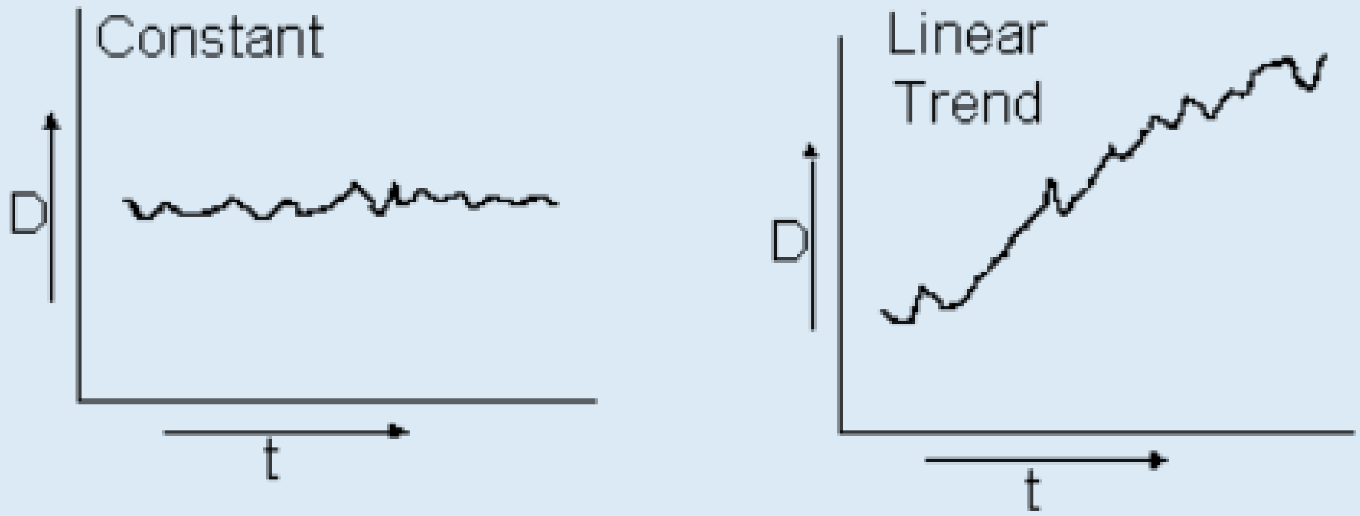
- Trend extrapolation

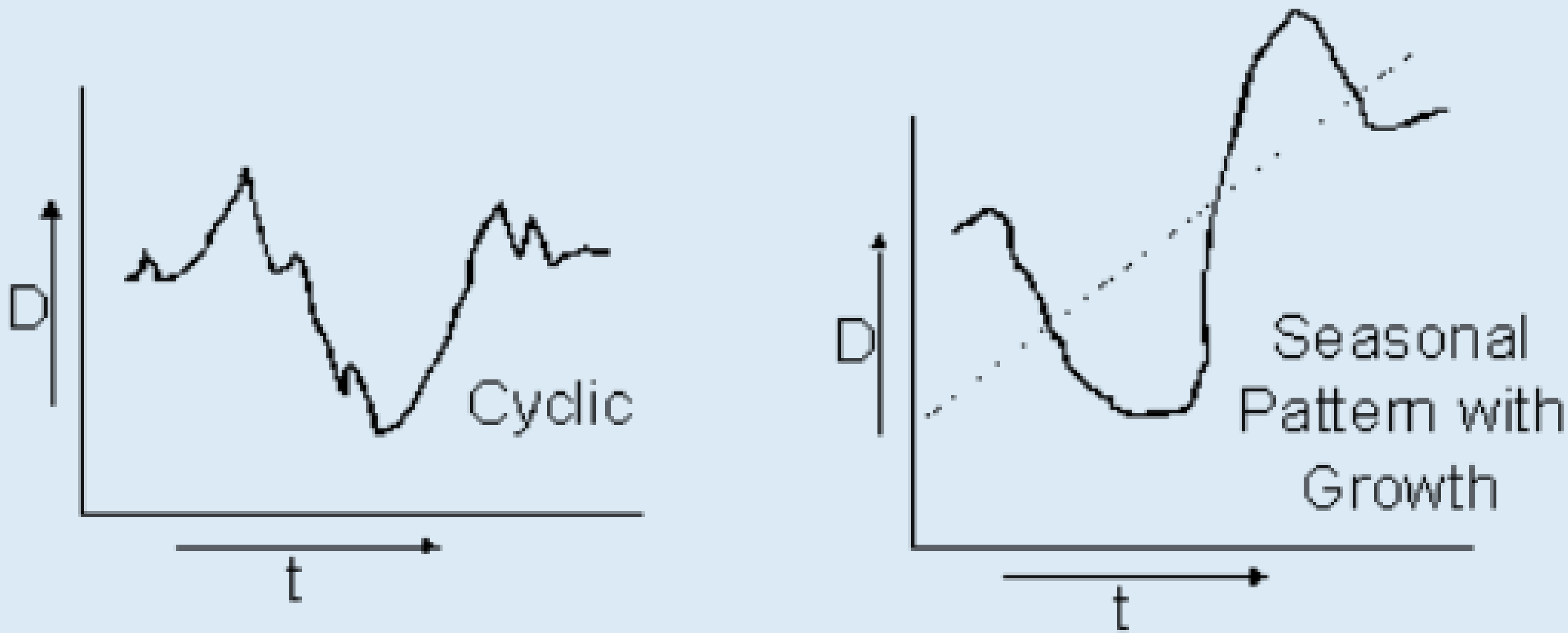
(d) Causal or econometric models

(e) Time - series analysis using stochastic models

- Box Jenkins model

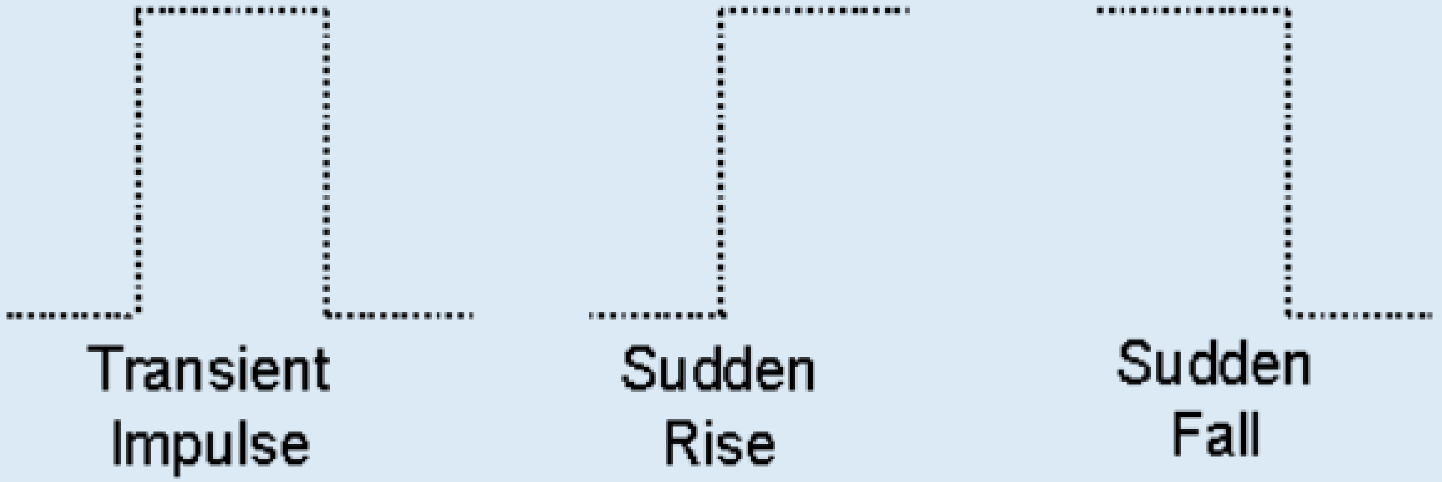
COMMONLY OBSERVED "NORMAL" DEMAND PATTERNS





D
Cyclic
t
D
Seasonal
Pattern with
Growth
t

ABNORMAL DEMAND PATTERNS



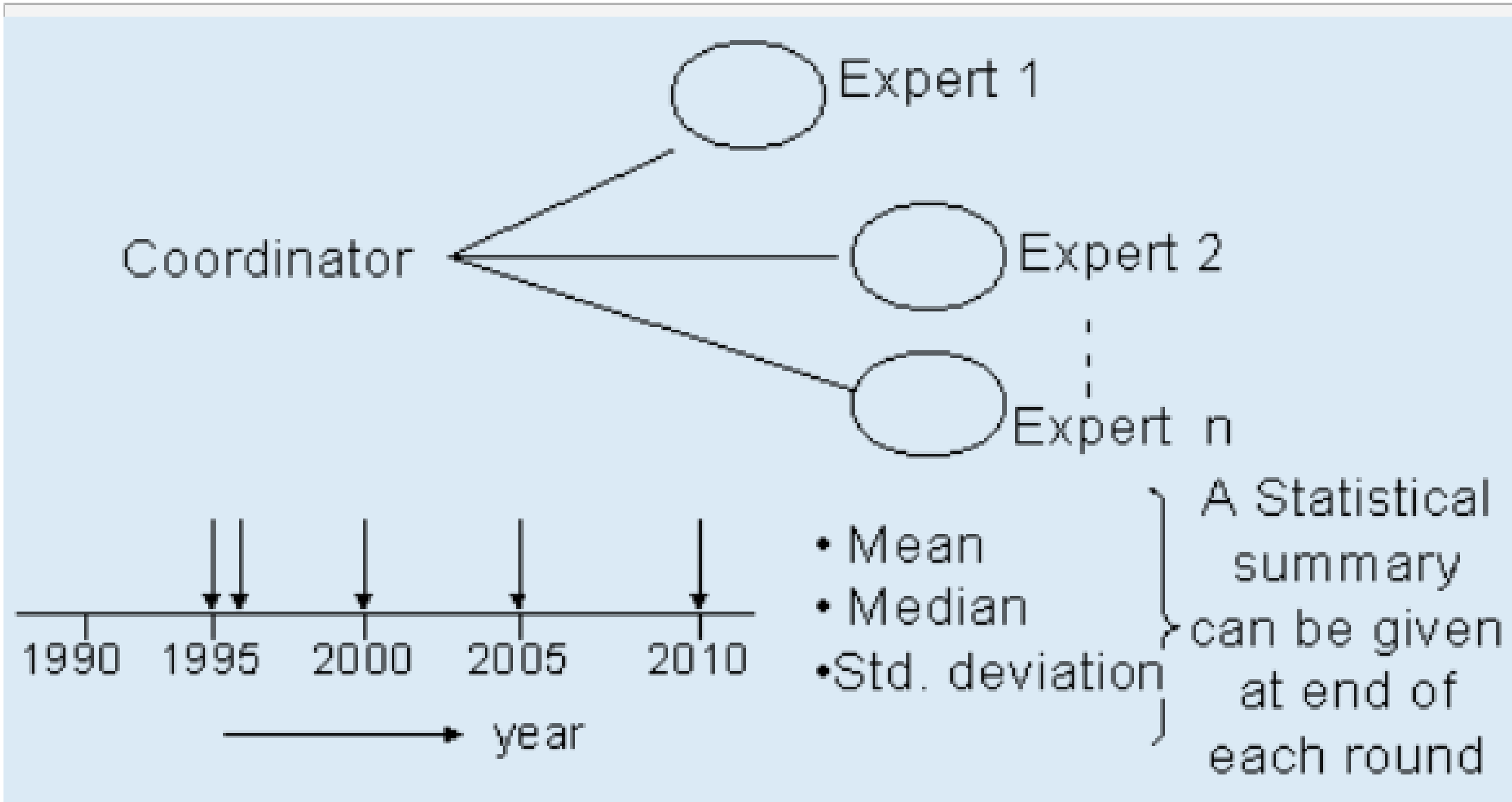
DELPHI

A structured method of obtaining responses from experts.

- Utilizes the vast knowledge base of experts
- Eliminates subjective bias and 'influencing' by members through anonymity
- Iterative in character with statistical summary at end of each round (Generally 3 rounds)
- Consensus (or Divergent Viewpoints) usually emerge at the end of the exercise.

HCP

DELPHI



Expert 1
Coordinator
Expert 2
Expert n
1990
1995
2000
2005
2010
year
• Mean
• Median
•Std. deviation
A Statistical summary can be given at end of each round

Month	Demand	3 months MA	6 months MA
JAN	199		
FEB	202		
MAR	199	200.00	
APR	208	203.00	
MAY	212	**206.33**	
JUN	194	203.66	202.33
JUL	214	205.66	207.83
AUG	220	208.33	210.83
SEP	219	216.66	213.13
OCT	234	223.33	217.46
NOV	219	223.00	218.63
DEC	233	227.66	225.13

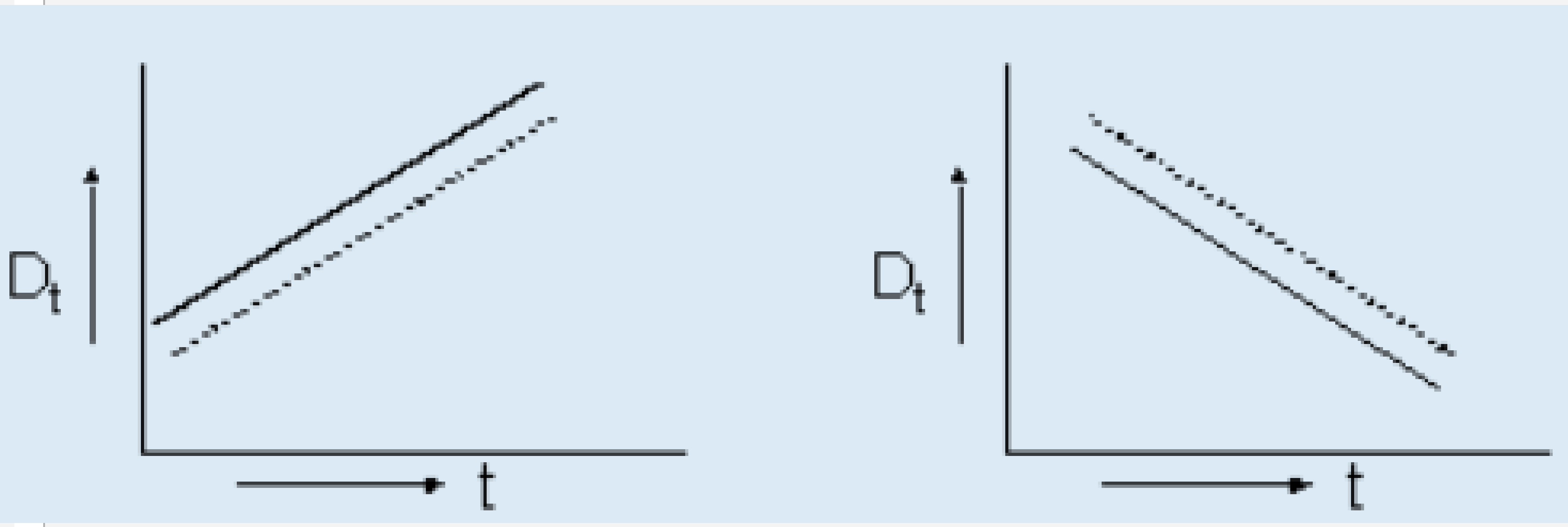
MOVING AVERAGES

- K PERIOD MA = AVERAGE OF K MOST RECENT OBSERVATIONS

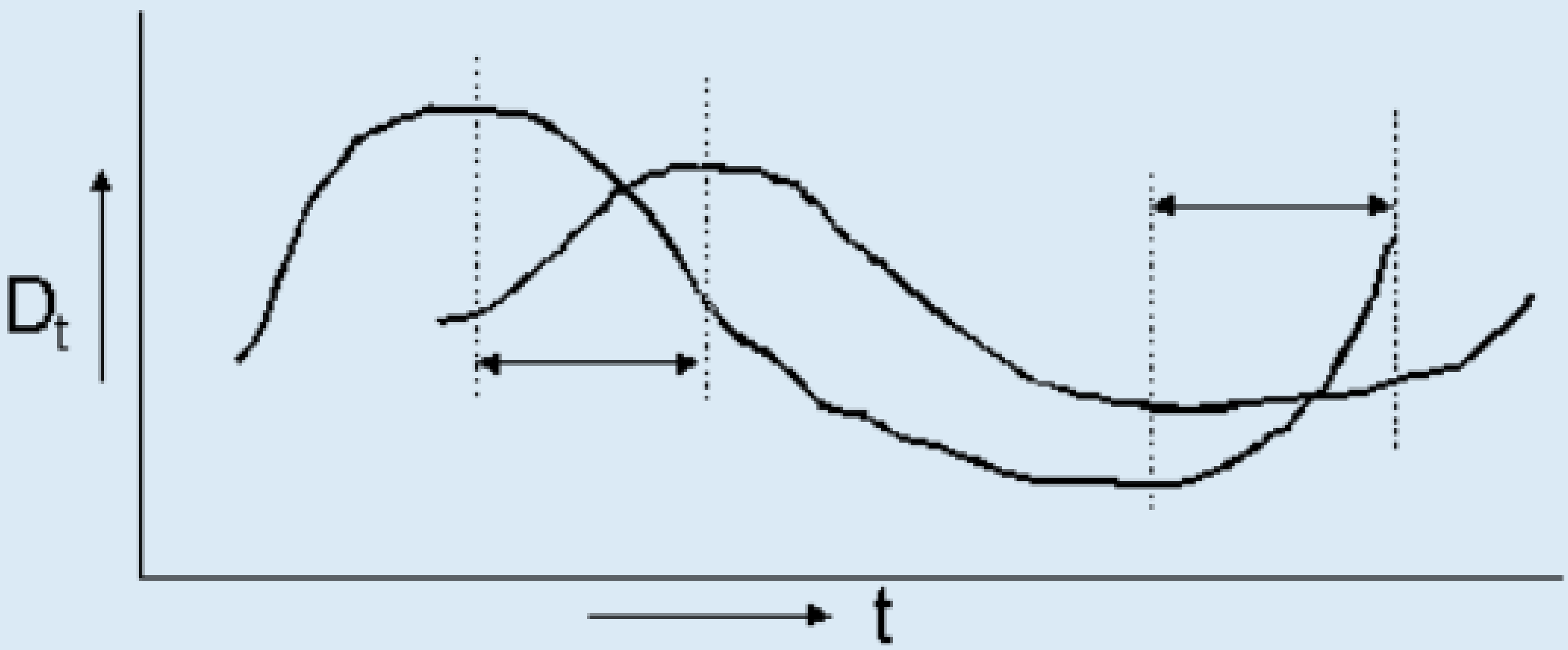
  For instance :
  3 PERIOD MA FOR MAY
  = Demands of Mar, Apr, May / 3
  = (199 + 208 + 121) / 3 = **206.33**

CHARACTERISTICS OF MOVING AVERAGES

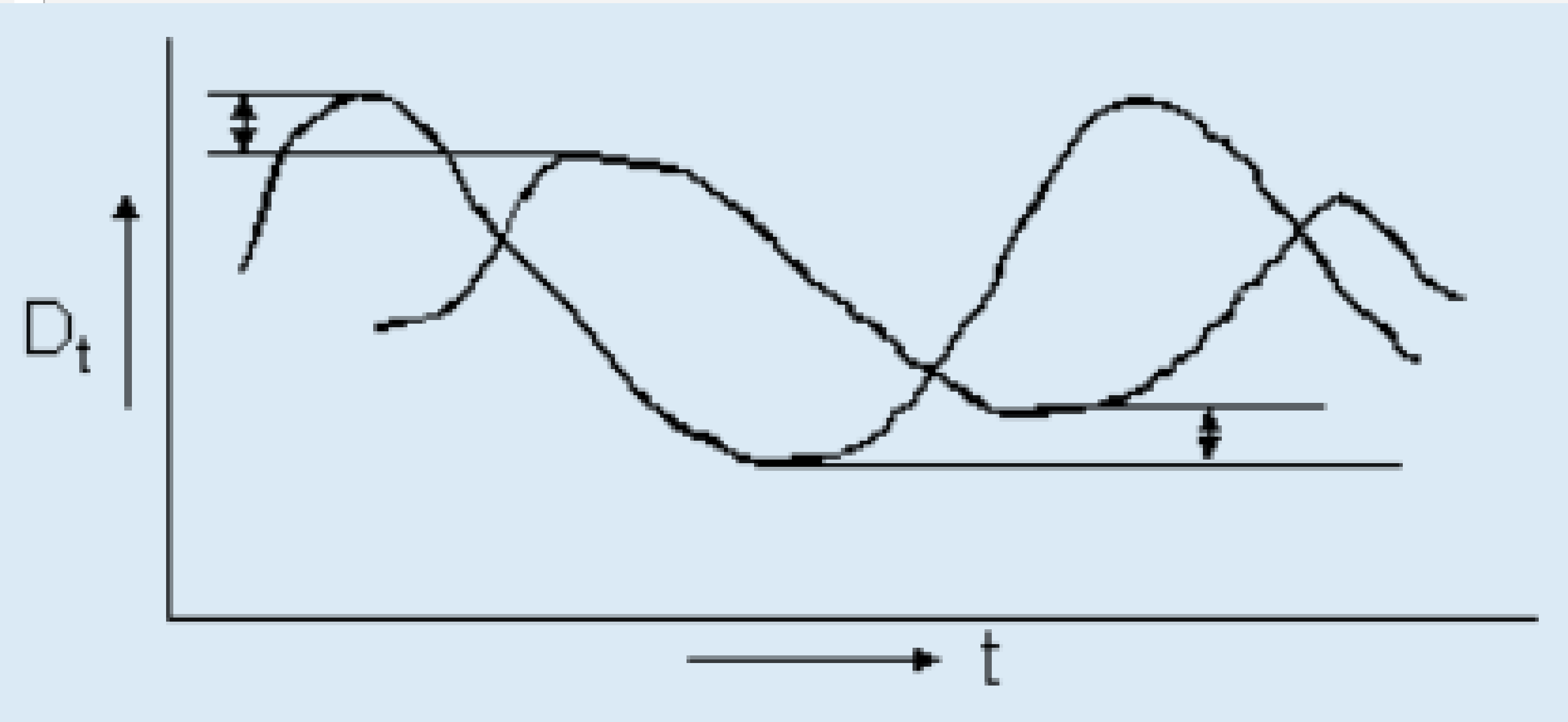
1) MOVING AVERAGES LAG A TREND



2) MOVING AVERAGES ARE OUT OF PHASE FOR CYCLIC DEMAND



3) MOVING AVERAGES FLATTEN PEAKS



EXPONENTIAL SMOOTHING

F_t = one period ahead forecast made at time time t

D_t = actual demand for period t

α = Smoothing constant (between 0 & 1)
(generally chosen values lie between 0.01 and 0.3)

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

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

$$= \alpha D_t + (1 - \alpha) [\alpha D_{t-1} + (1 - \alpha)^2 F_{t-2}]$$

$$= \ldots\ldots$$

$$= \alpha [D_t + (1 - \alpha) D_{t-1} + (1 - \alpha)^2 D_{t-2} + \ldots\ldots + (1 - \alpha)^{t-1} D_1 + (1 - \alpha)^t F_0]$$

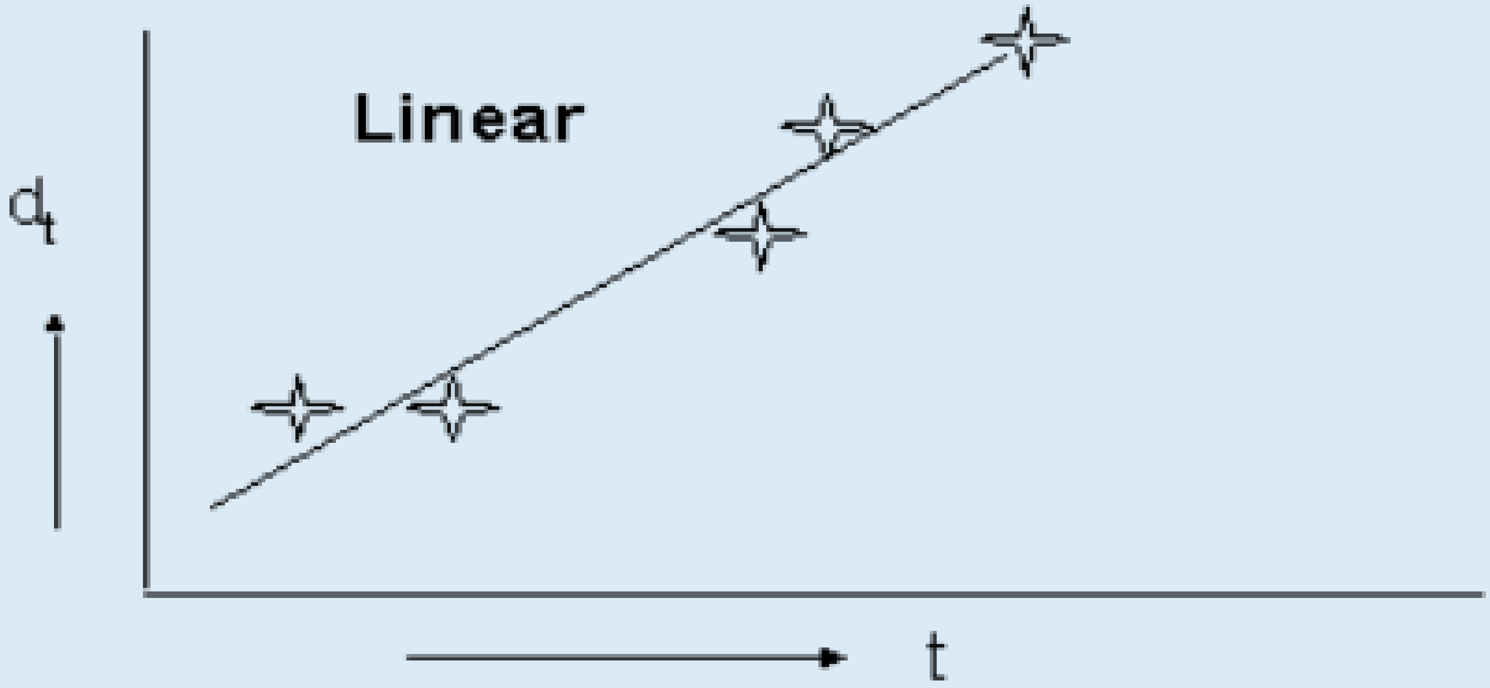
Weightages given to past data decline exponentially.

MOVING AVERAGES AND EXPONENTIAL SMOOTHING

(Equivalence between α & N :)

$$\alpha = 2 / (N+1)$$

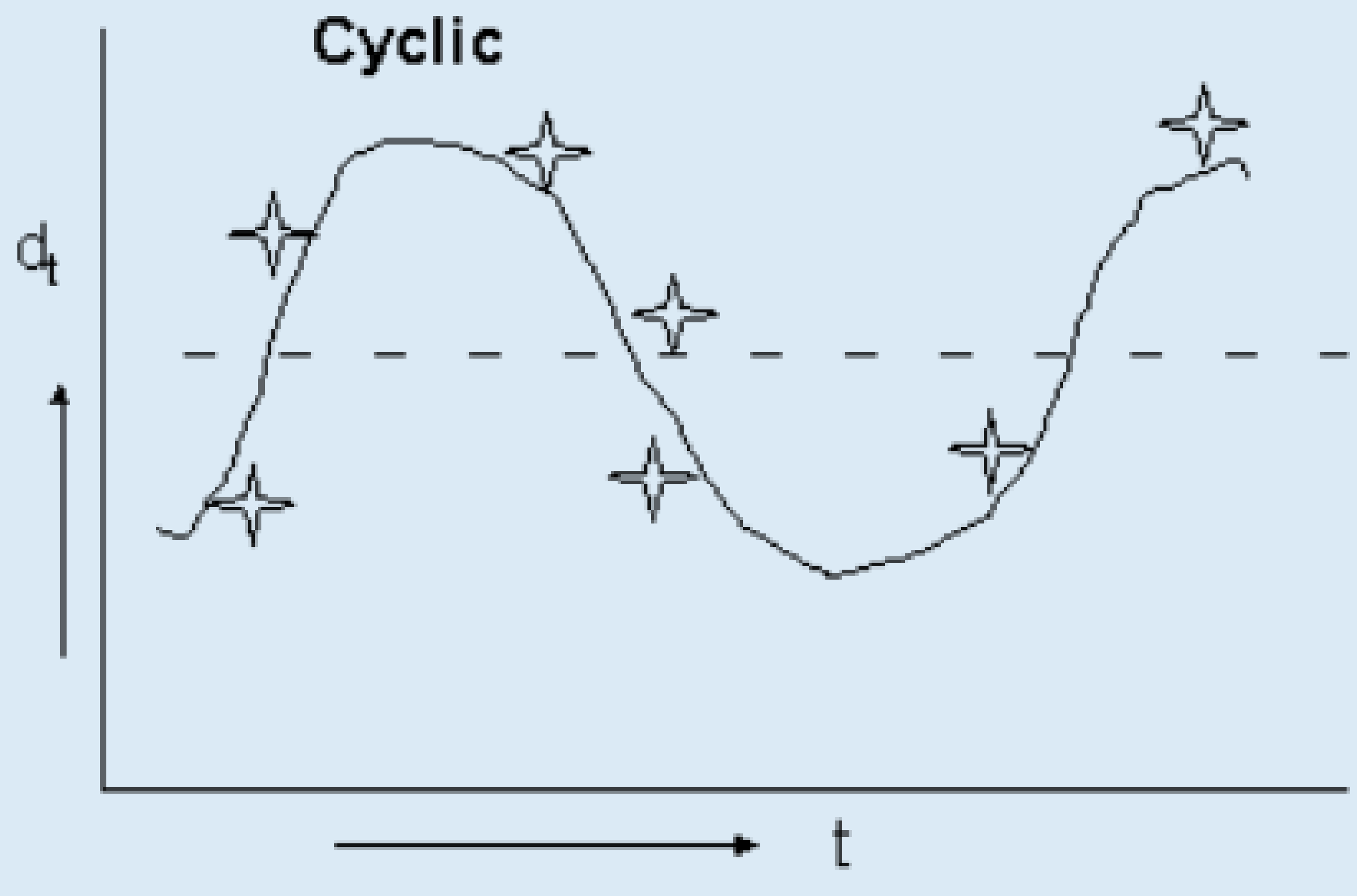
COMMON REGRESSION FUNCTIONS



d_t' forecast

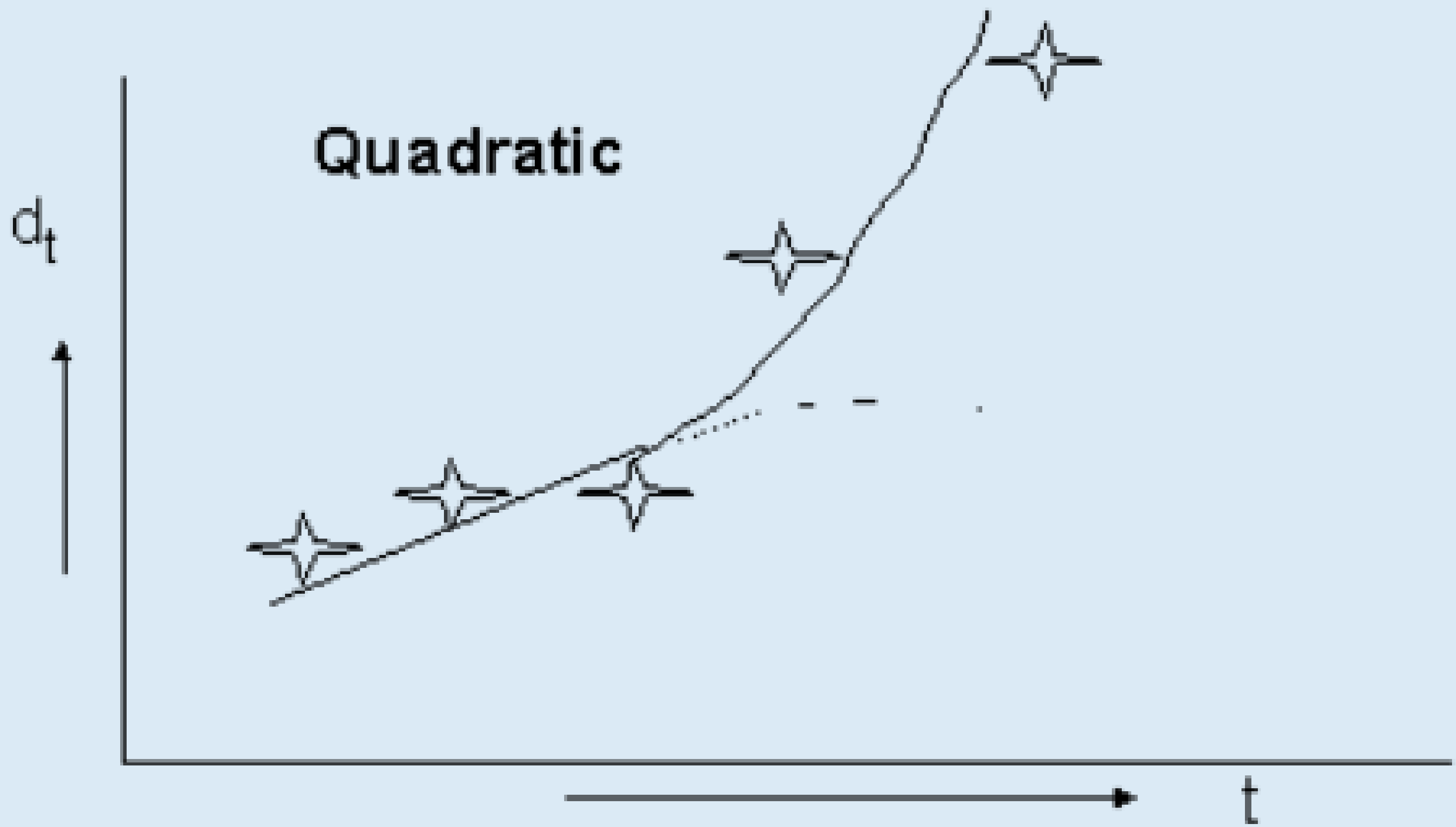
d_t actual demand (for time period t)

$d_t' = a + bt$ (parameters a, b)



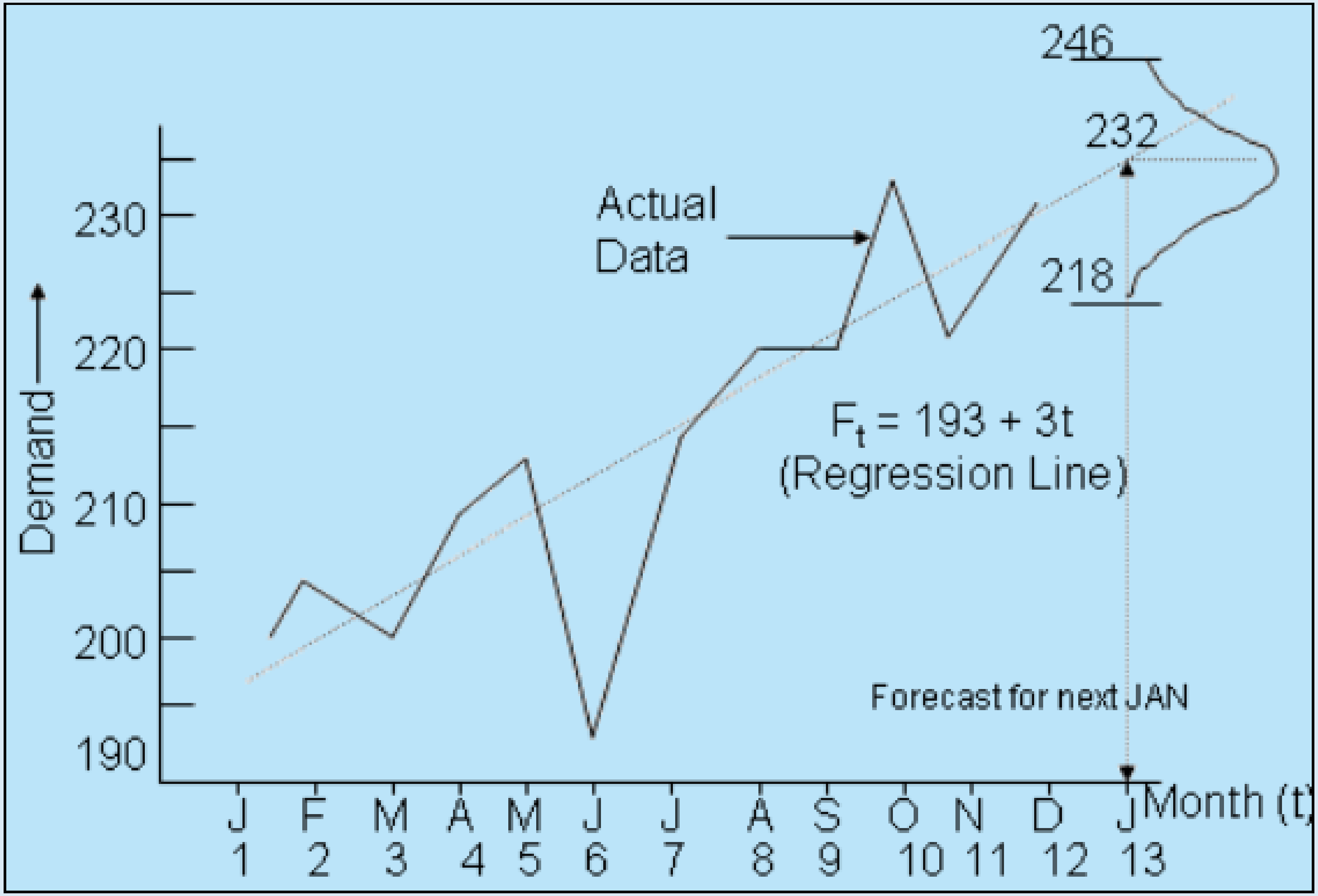
$$d_t' = a + u \cos(2\pi/n)t + v \sin(2\pi/n)t \quad \text{(parameters } a, u, v\text{)}$$

Parameters Determined by Minimizing the Sum of Squares of errors



$$d_t' = a + bt + ct^2 \quad \text{(parameters a,b,c)}$$

REGRESSION


246
232
218
Actual
Data
230
220
210
200
190
Demand
$F_t = 193 + 3t$
(Regression Line)
Forecast for next JAN
Month (t)
J F M A M J J A S O N D J
1 2 3 4 5 6 7 8 9 10 11 12 13

$$\text{Standard error of estimate} = \sqrt{\frac{\sum_{t=1,n} (D_t - F_t)^2}{n-f}}$$

$$= 7.32$$

Where

D_t = actual demand for period t

F_t = forecast for period t

n = no. of data points

f = degrees of freedom lost (2 in this case)

95 % confidence limits for forecast of next JAN $\simeq$ 232 ± 14 (2 sigma limits)

TIME SERIES ANALYSIS

- Time series decomposed into
  - Trend
  - Seasonality
  - Cycle
  - Randomness

  And Forecast generated from these components

- Trend, T_t
- Seasonality S_t
- Cycle C_t
- Randomness R_t

EXAMPLE 1

	Past Sales	Average Sales(1000/4)	Seasonal Factor
Spring	200	250	200/250 = 0.8
Summer	350	250	350/250 = 1.4
Fall	300	250	300/250 = 1.2
Winter	150	250	150/250 = 0.6
TOTAL = 1000			

	Expected Next year demand	Average Sales (1100/4)	Seasonal Factor	Next Year Forecast
Spring	↓	275	200/250 = 0.8	275 * 0.8 = 220
Summer		275	350/250 = 1.4	275 *1.4 = 385
Fall		275	300/250 = 1.2	275 *1.2 = 330
Winter		275	150/250 = 0.6	275 * 0.6 = 165
TOTAL	= 1100			

EXAMPLE 2

- Computing Trend & Seasonal Factor on a 2 year demand history

Quater	Amount	Quater	Amount
I - 2000	300	I - 2001	520
II - 2000	200	II - 2001	420
III - 2000	220	III - 2001	400
IV - 2000	530	IV - 2001	700

HCP

Quarter	Demand	From trend equation	Ratio of actual/trend	Seasonal factor
2000		Tt = 170 + 55t		
I	300	225	1.33 → I	1.25
II	200	280	0.71 → II	0.78
III	220	335	0.66 → III	0.69
IV	530	390	1.36 → IV	1.25
2001				
I	520	445	1.17	
II	420	500	0.84	
III	400	555	0.72	
IV	700	610	1.15	

- Forecast for 2002 using Trend and Seasonal factors

	Trend	Seasonal Factor	Forecast
I - 2002	[170+ 55*09]	1.25	831
II - 2002	[170+ 55*09]	0.78	562
III - 2002	[170+ 55*09]	0.69	535
IV - 2002	[170+ 55*09]	1.25	1,038
Trend * Seasonal factor = Forecast			

EXAMPLE 3

- For the given demand history prepare a forecast using decomposition

Period	Actual	Period	Actual
1	300	5	416
2	540	6	760
3	885	7	1191
4	580	8	760

Period X	Actual Y	Period Average	Seasonal Factor	Deseasonalised demand
1	300	358	0.527	568.99
2	540	650	0.957	564.09
3	885	1038	1.529	578.92
4	580	670	0.987	587.79
5	416		0.527	789.01
6	760		0.957	793.91
7	1191		1.529	779.08
8	760		0.687	770.21
TOTAL	**5432**	**2716**	**8.0**	
AVERAGE	**679**	**679**	**1.0**	

Period X	Deseasonalised demand	y	x^2	xy
1	568.99	358	1	569.0
2	564.09	650	4	1128.2
3	578.92	1038	9	1736.7
4	587.79	670	16	2351.2
5	789.01		25	3945.0
6	793.91		36	4763.4
7	779.08		49	5453.6
8	770.21		64	6161.7
TOTAL	**5432**		**204**	**26,108.8**
AVERAGE	**679**			

The regression equation for deseasonalized data:

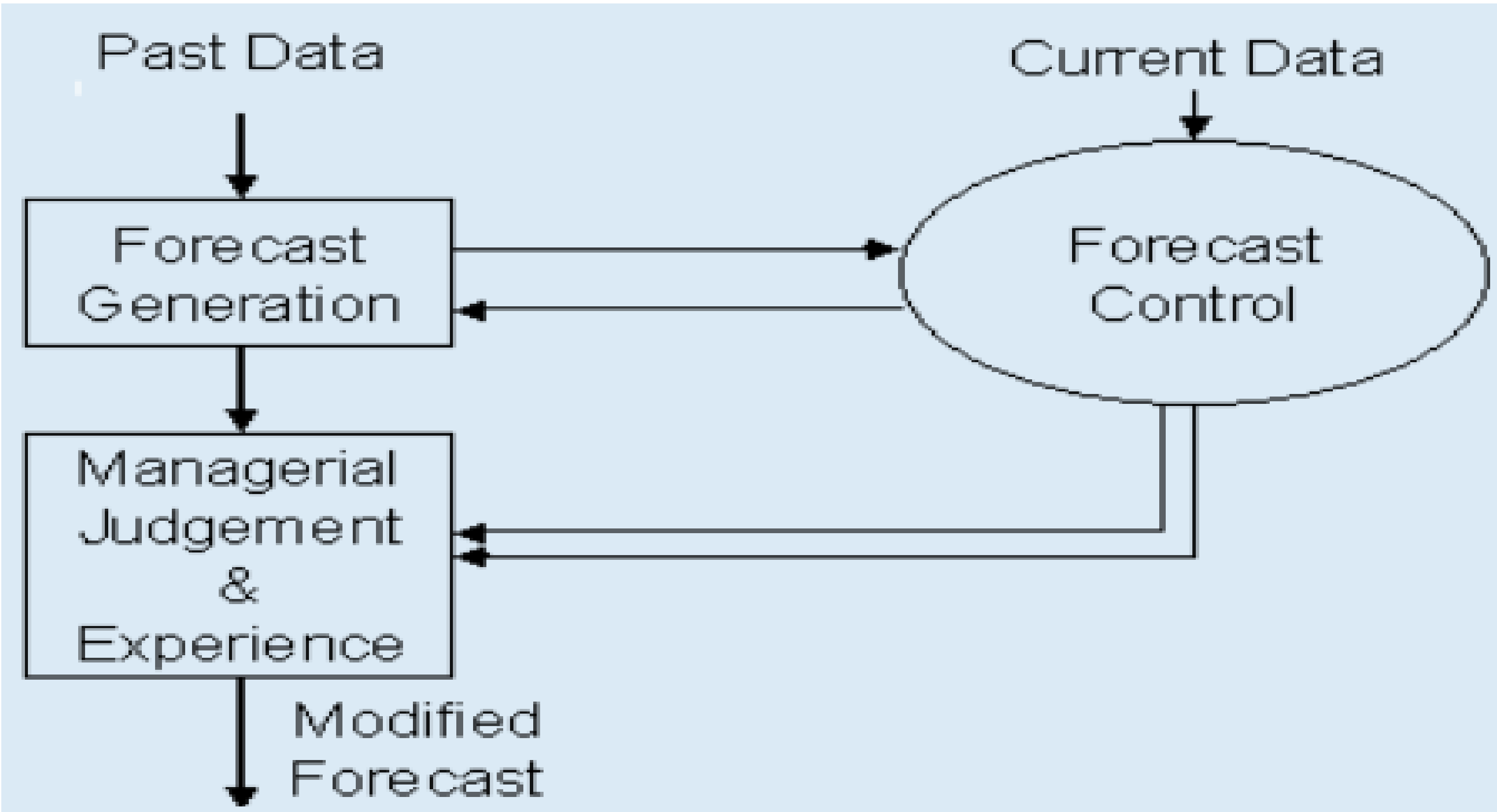
$$b = \frac{26108 - (8)(4.5)(679)}{9204) - (8)(4.5)^2} = 39.64 \quad \text{(slope of st. line)}$$

$$a = \bar{Y} - b\bar{x} = 679 - 39.64(4.5) = 500.6 \quad \text{(intercept of st.line)}$$

Thus, Y = 500.6 + 39.64x is the result of the deseasonalized regression line

Period	Trend forecast		Seasonal factor		Final forecast
9	857.4	*	0.527	=	452.0
10	897.0	*	0.957	=	858.7
11	936.7	*	1.529	=	1431.9
12	976.3	*	0.987	=	963.4

Forecasting System



$$\overline{MR} = |(F_t - D_t) - (F_{t-1} - D_{t-1})|$$

(Moving Range)

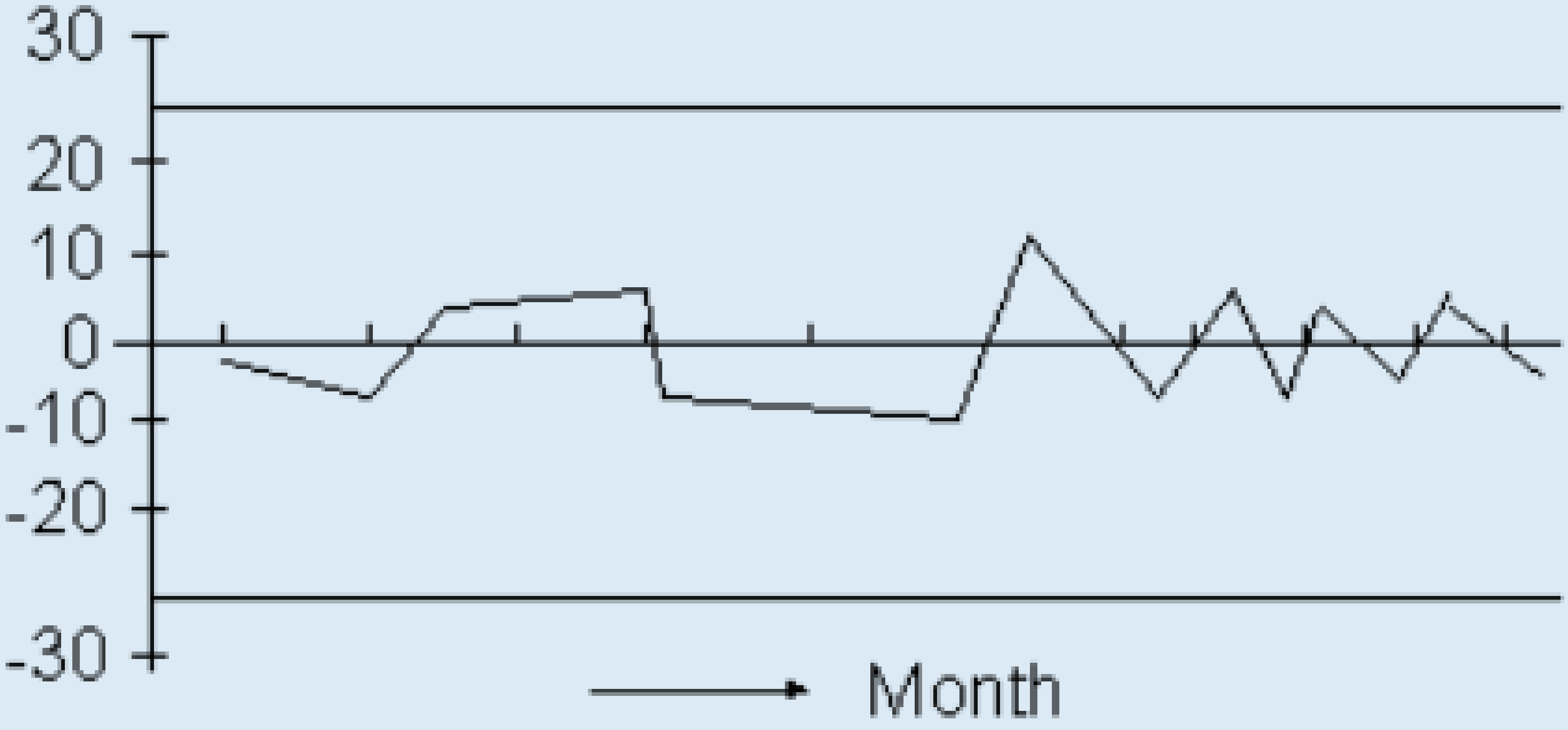
$$\overline{MR} = \Sigma\, \overline{MR} / (n - 1)$$

(There are n-1 moving ranges for n period)

Upper Control Limit (UCL) = + 2.66 MR

Lower Control Limit (LML) = - 2.66 MR

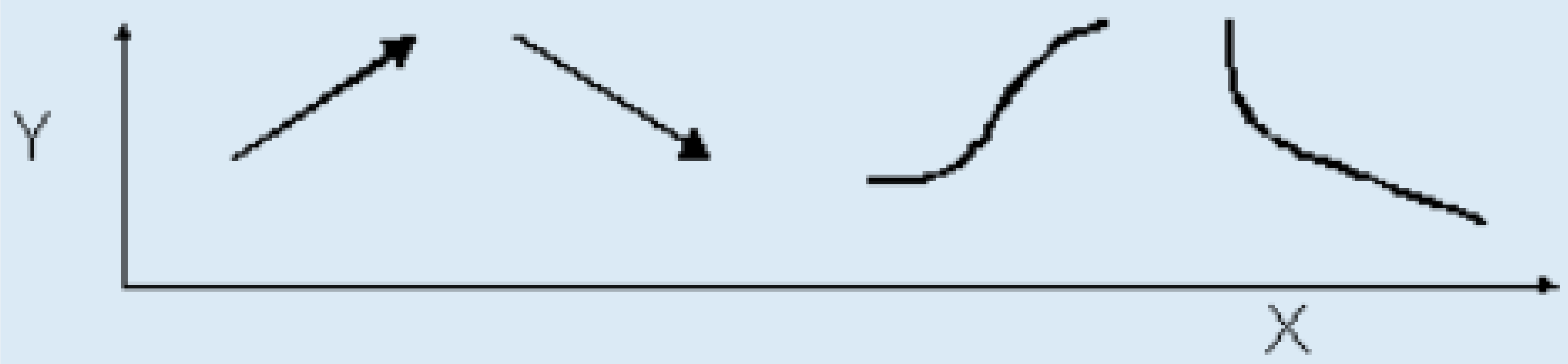
VARIABLE TO BE PLOTTED = $(F_t - D_t)$

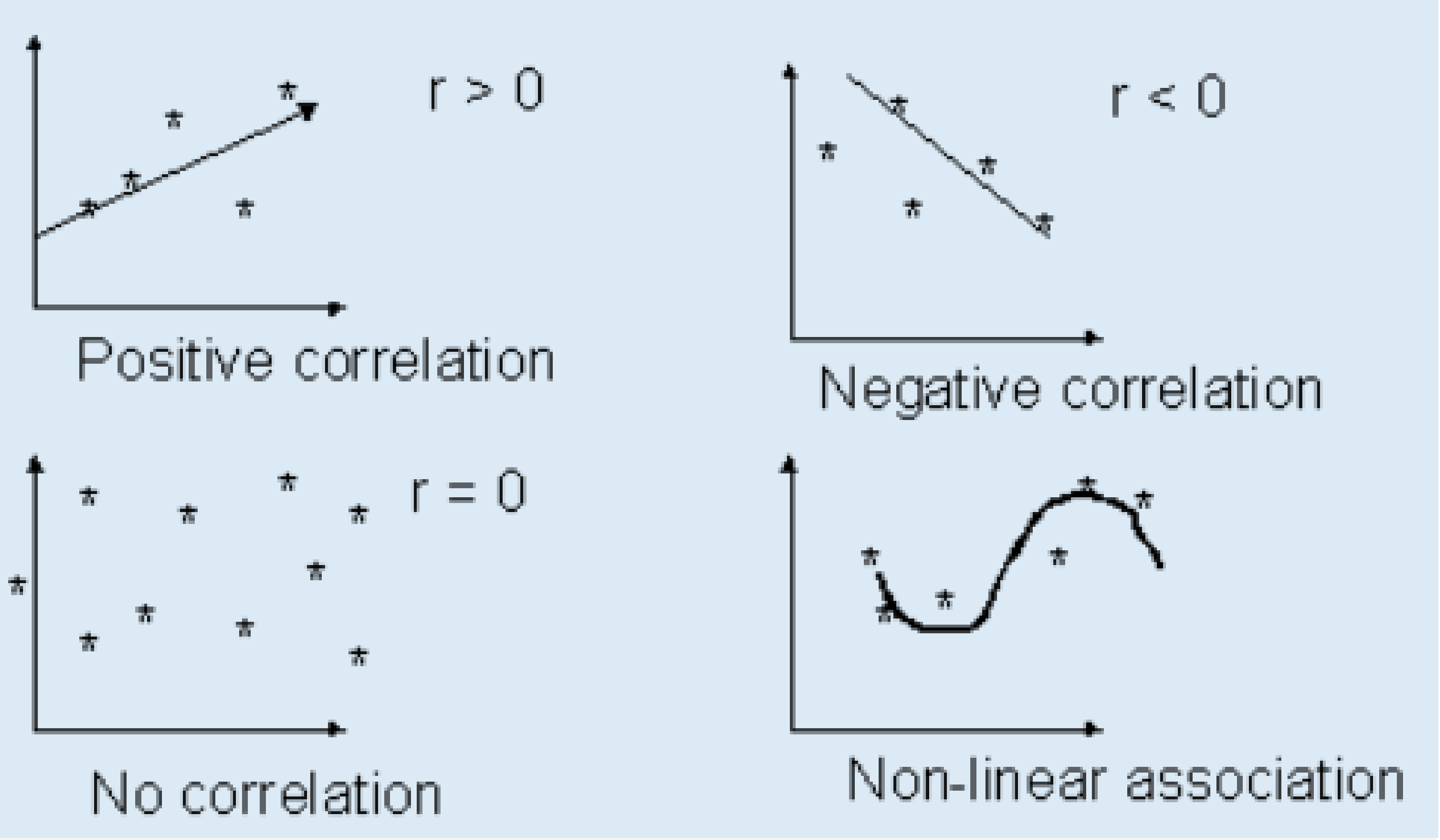


(Control Chart for Example)

CORRELATION vs REGRESSION ?

- Correlation examines if there is an association between two variables, and if so to what extent.
- Regression establishes an appropriate relationship between the variables




r > 0
Positive correlation
r < 0
Negative correlation
r = 0
No correlation
Non-linear association

THE CORRELATION COEFFICIENT

- Pearson’s correlation coefficient,

$$= \frac{(1/n)\ \text{Sum}\ [(X-\overline{X})\ (Y-\overline{Y})]}{\text{sigma}\ X\ \text{sigma}\ Y}$$

(The numerator is the Co-variance between X and Y)

Advertisement expenditure (X) vs Sales (Y) figures for 10 years in Lacs of Rupees.

S.No.	X	Y	$x = X - \bar{X}$	$y = Y - \bar{Y}$	x2	y2	xy
1	50	700	21	274	441	75,076	5,754
2	50	650	21	274	441	50,176	4,704
3	50	600	21	174	441	30,276	3,654
4	40	500	11	74	121	5,476	814
5	30	450	1	24	1	576	24
6	20	400	-9	-26	81	676	234
7	20	300	-9	-126	81	15,876	1,134
8	15	250	-14	-176	196	30,976	2,464
9	10	210	-19	-216	361	46,656	4,104
10	5	200	-24	-226	576	51,076	5,424
Total	290	4260	0	0	2,740	3,06,840	28,310

$\overline{X} = 290/10 = 29$: $\overline{Y} = 4260/10 = 426$

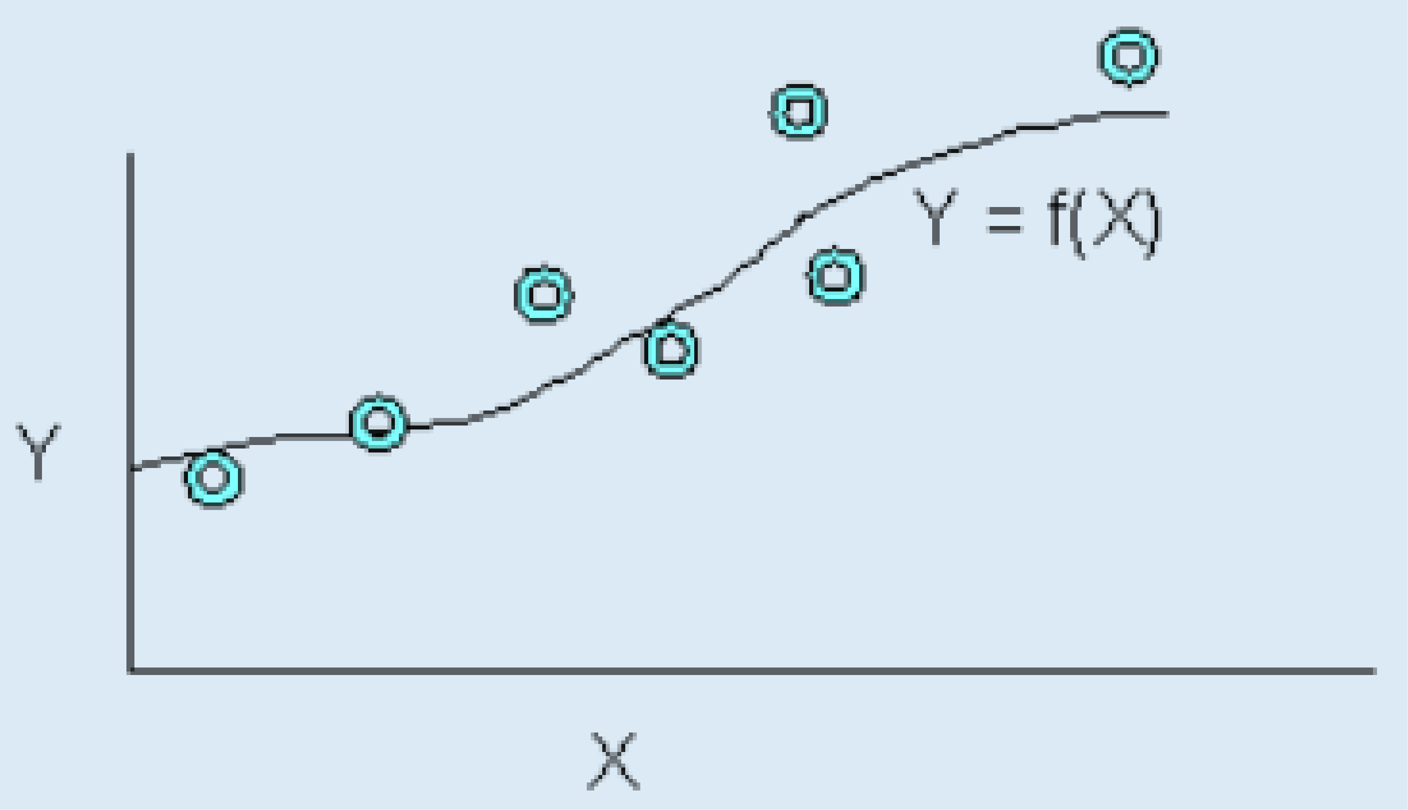
$r = \Sigma xy / [\Sigma x^2 \Sigma y^2]^{1/2}$

$= 28310 / (2740 * 306840)^{1/2} = 0.976$

Coefficient of Determination = $r^2 = 0.953$

What is Regression ?

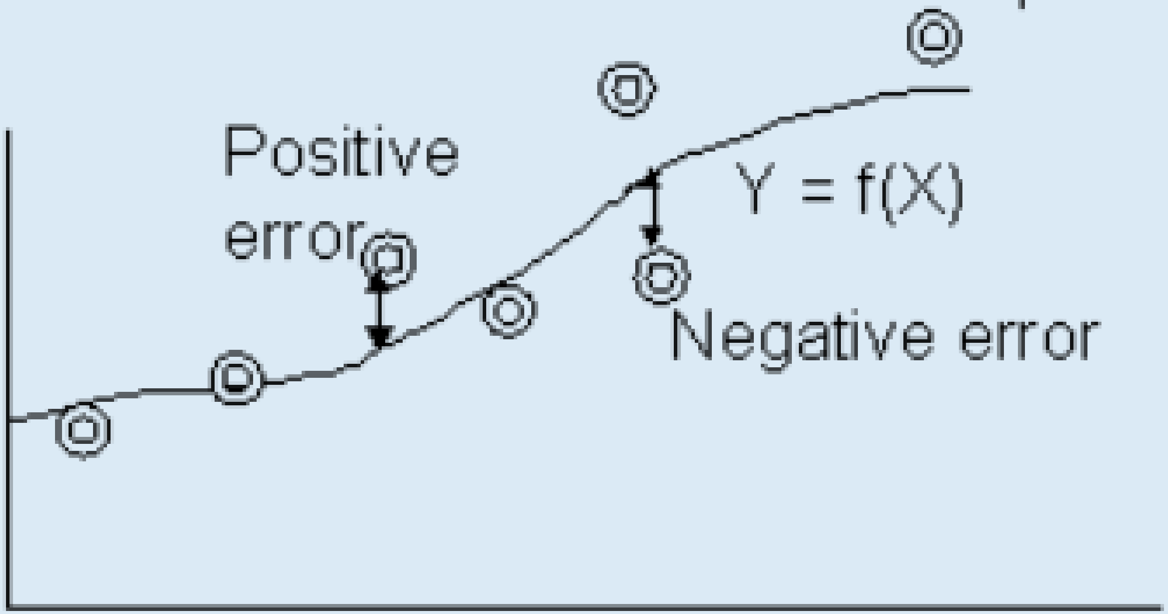
- Discovering how a dependent variable (Y) is related to one or more independent variables (X)



Criterion for best fit ?

Minimize ?

Mean error
Mean absolute error
Sum of Squares of Errors



Least Squares Criterion is the generally preferred criterion

Fitting a Straight Line

$F_t = a + bt$ is the equation of the line to be fitted

- F_t is the fitted function for time t
- D_t is the actual demand for period t
- Past data is available for n periods
- Parameters a & b have to be estimated from the data using least squares criterion

Least Squares Normal Equations

$$SSE = \Sigma(Dt - Ft)^2 = \Sigma(Dt - a - bt)^2$$

To minimize (SSE)

$$d(SSE)/da = \Sigma\, 2(Dt - a - bt)(-1) = 0$$

$$d(SSE)/db = \Sigma\, 2(Dt - a - bt)(-t) = 0$$

Or

$$a(n) + b(\Sigma t) = \Sigma Dt$$

$$a(\Sigma t) + b(\Sigma t^2) = \Sigma t\, Dt$$

These are two linear simultaneous equations in the two unknown parameters a and b which can be solved by any of the well known methods eg *Cramer's Rule*.These equations are called Least Squares Normal Equations

Least Squares Normal Equations

$$a(n) + b(\Sigma t) = \Sigma Dt \qquad a(\Sigma t) + b(\Sigma t^2) = \Sigma t\, Dt$$

(Least Squares Normal Equations)

$$a = \frac{\begin{vmatrix} \Sigma Dt & \Sigma t \\ \Sigma tDt & \Sigma t^2 \end{vmatrix}}{\begin{vmatrix} n & \Sigma t \\ \Sigma t & \Sigma t^2 \end{vmatrix}} = \frac{\Sigma Dt\, \Sigma t^2 - \Sigma t\, \Sigma tDt}{n\, \Sigma t^2 - (\Sigma t)^2} \qquad b = \frac{\begin{vmatrix} n & \Sigma Dt \\ \Sigma t & \Sigma tDt \end{vmatrix}}{\begin{vmatrix} n & \Sigma t \\ \Sigma t & \Sigma t^2 \end{vmatrix}} = \frac{n\, \Sigma tDt - \Sigma t\, \Sigma Dt}{n\, \Sigma t^2 - (\Sigma t)^2}$$

Organizing Computations

S.No.	ti	Di	tiDi	ti2
1	t1	D1	t1D1	t12
2	t2	D2	t2D2	t22
.				
n	tn	Dn	tnDn	tn2s
TOTAL	? ti	? Di	? tiDi	? ti^2

Computational Simplifications

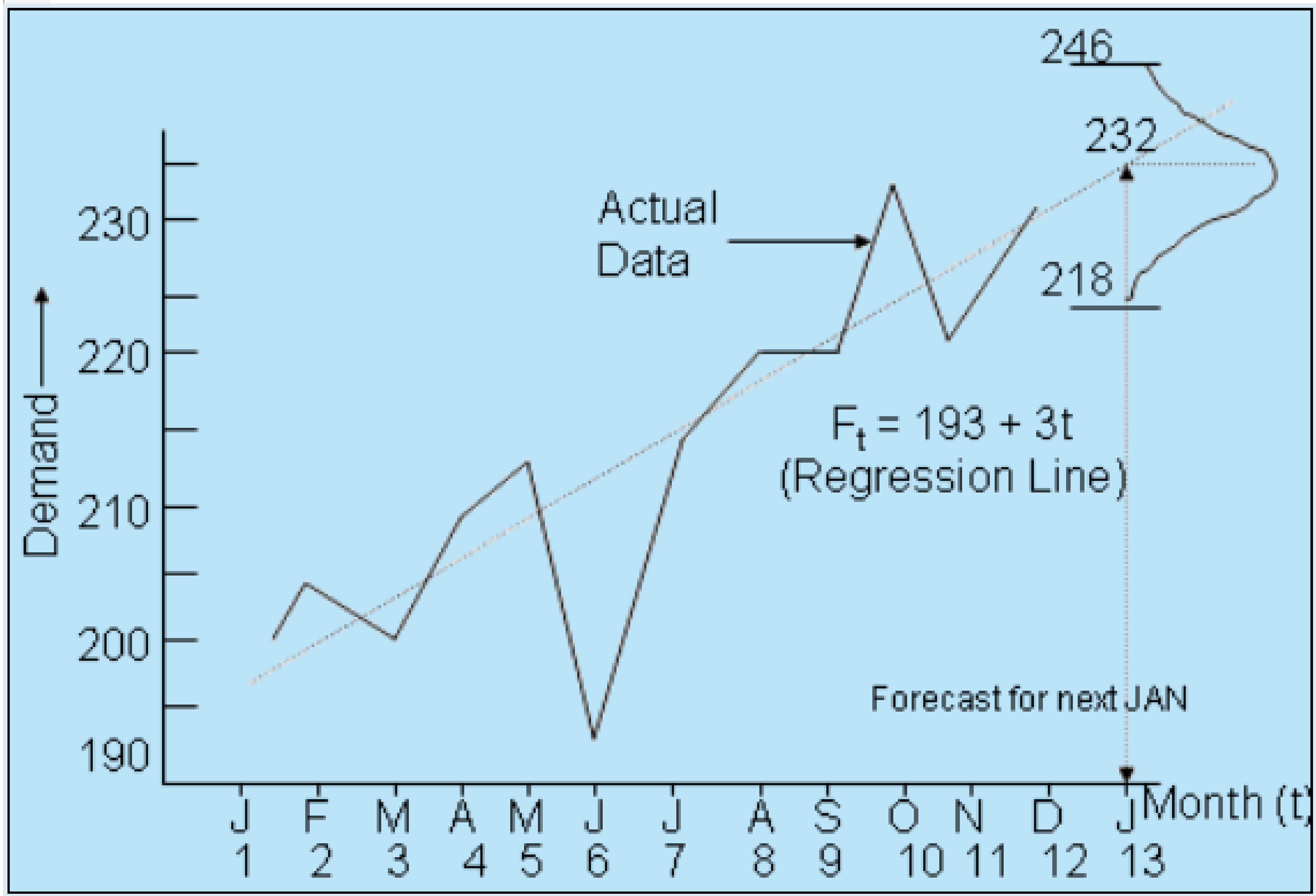
- By choosing an origin and scale of data such that $\Sigma t = 0$,the values of the parameters become :

$$a = \Sigma Dt / n$$
$$b = \Sigma tDt / \Sigma t^2$$

(This is useful for equally spaced data with even or odd number of data points)

DEMAND HISTORY

Month	Demand
JAN	199
FEB	202
MAR	199
APR	208
MAY	212
JUN	194
JUL	214
AUG	220
SEP	219
OCT	234
NOV	219
DEC	233

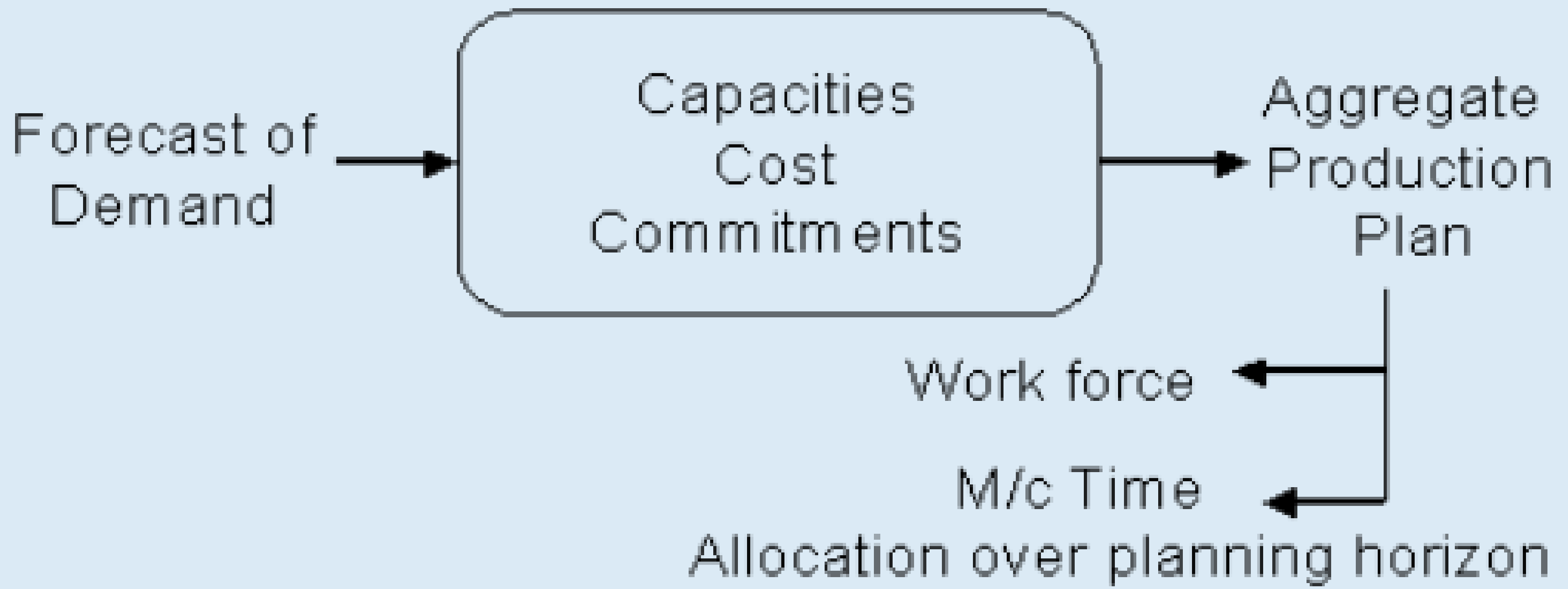


246
232
218
230
220
210
200
190
Demand
Actual
Data
F_t = 193 + 3t
(Regression Line)
Forecast for next JAN
J F M A M J J A S O N D J
1 2 3 4 5 6 7 8 9 10 11 12 13
Month (t)

AGGREGATE PRODUCTION PLANNING

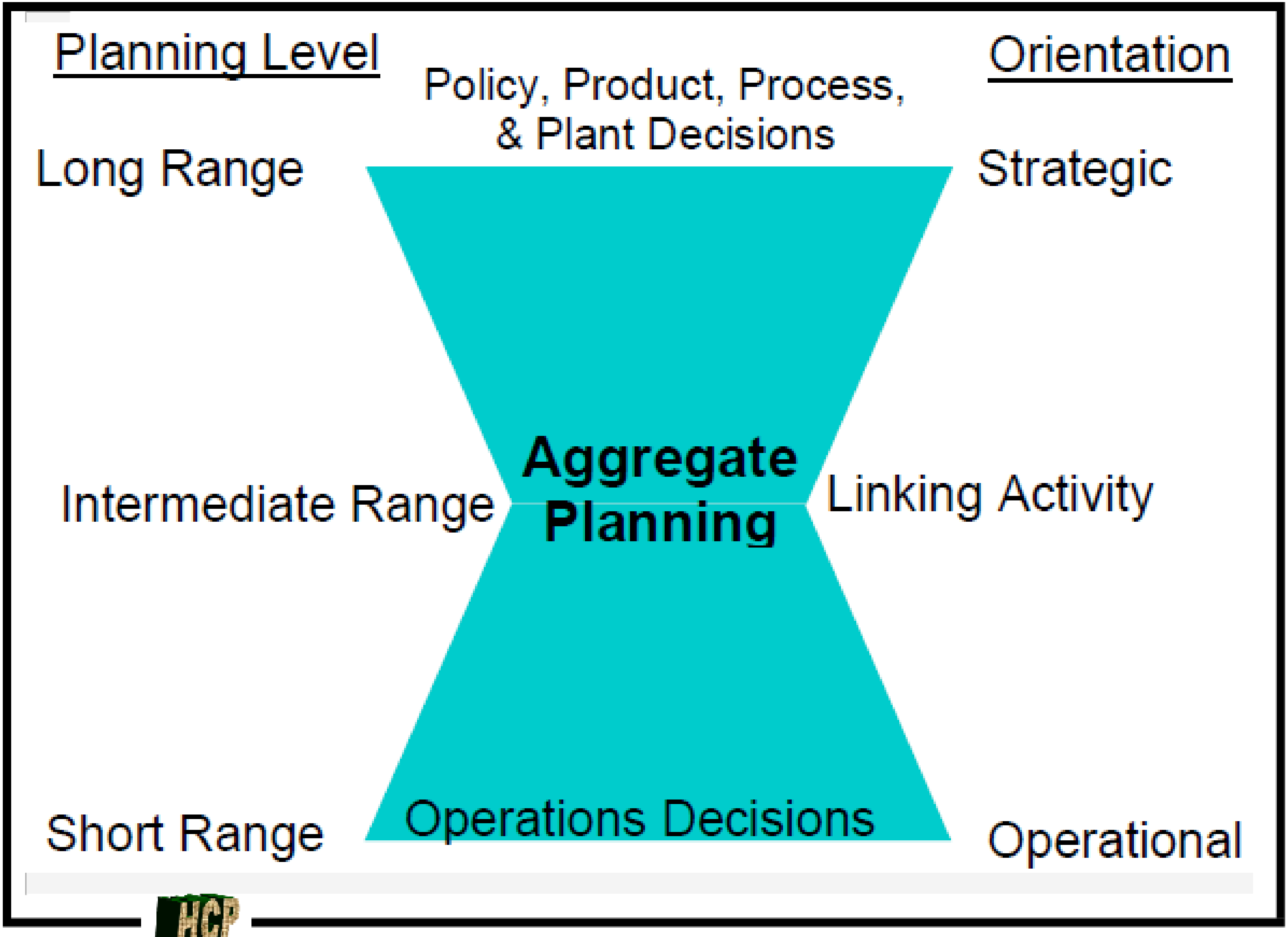
- Concerned with planning overall production of all products combined (in tonnes of steel, litres of paint etc.) Over a planning horizon (generally next 3 to 6 months) for a given (forecast) demand schedule.

AGGREGATE PRODUCTION PLANNING



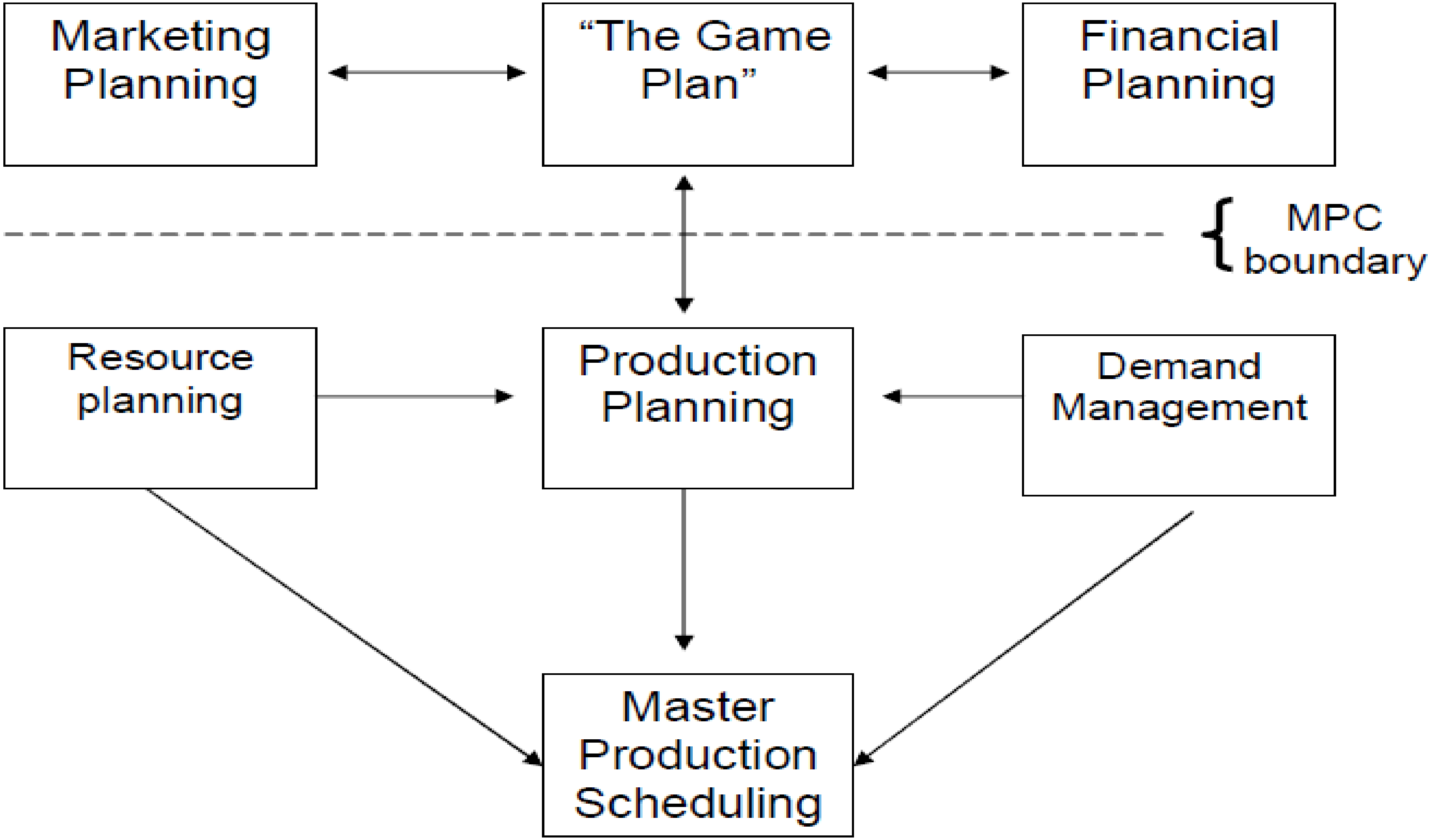
A good production plan should

- be consistent with organisational policy
- meet demand requirements
- be within capacity constraints
- minimizes costs

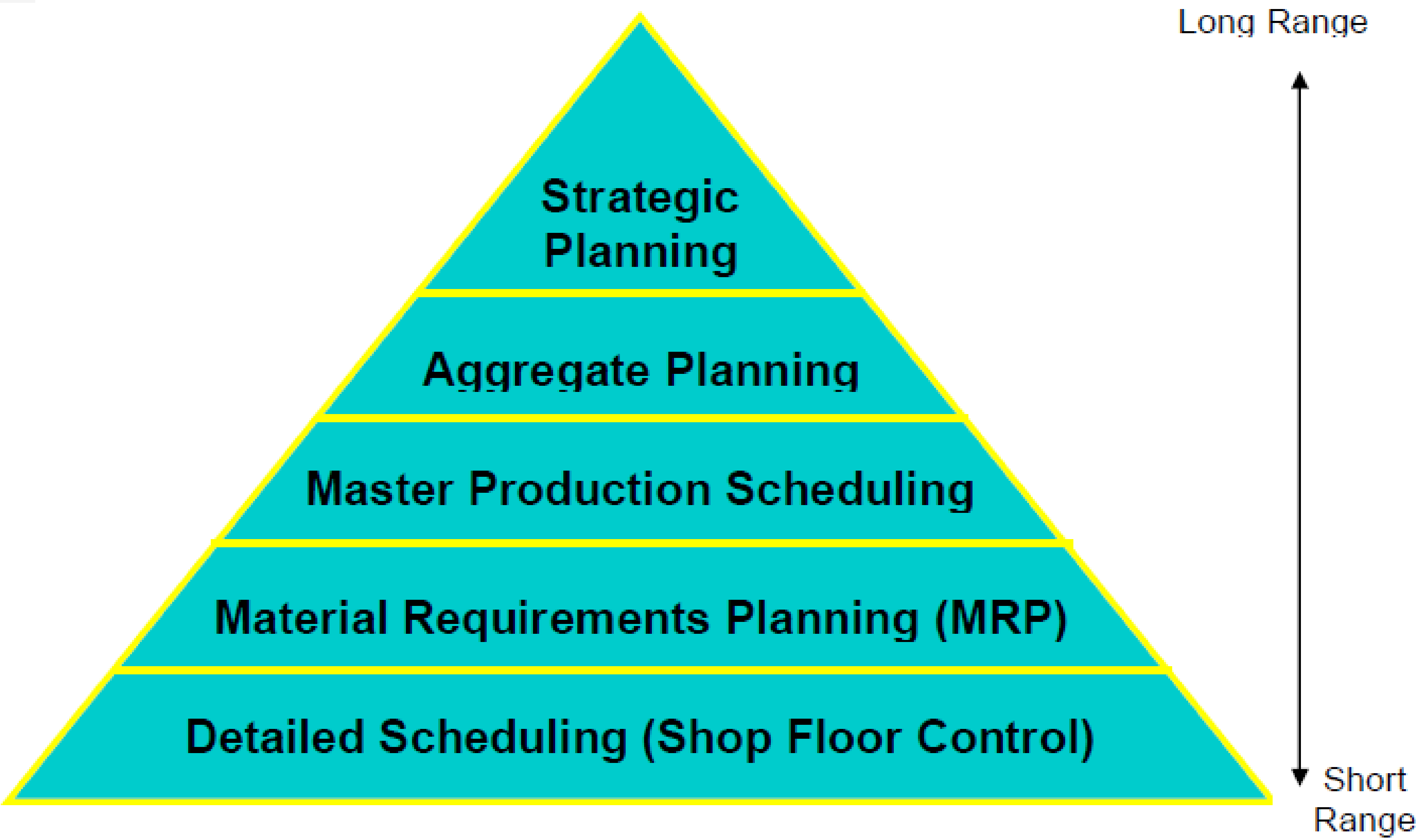

Planning Level
Orientation
Policy, Product, Process, & Plant Decisions
Long Range
Strategic
Aggregate Planning
Intermediate Range
Linking Activity
Operations Decisions
Short Range
Operational

- · LONG RANGE
  - products
  - Processes
  - plant location
  - plant layout
- INTERMEDIATE RANGE (Aggregates)
  - output rates
  - employment levels
  - inventory
  - subcontracting
- SHORT RANGE
  - job assignments
  - machine loading
  - job sequencing
  - lot sizes

Key Linkages of Production Planning

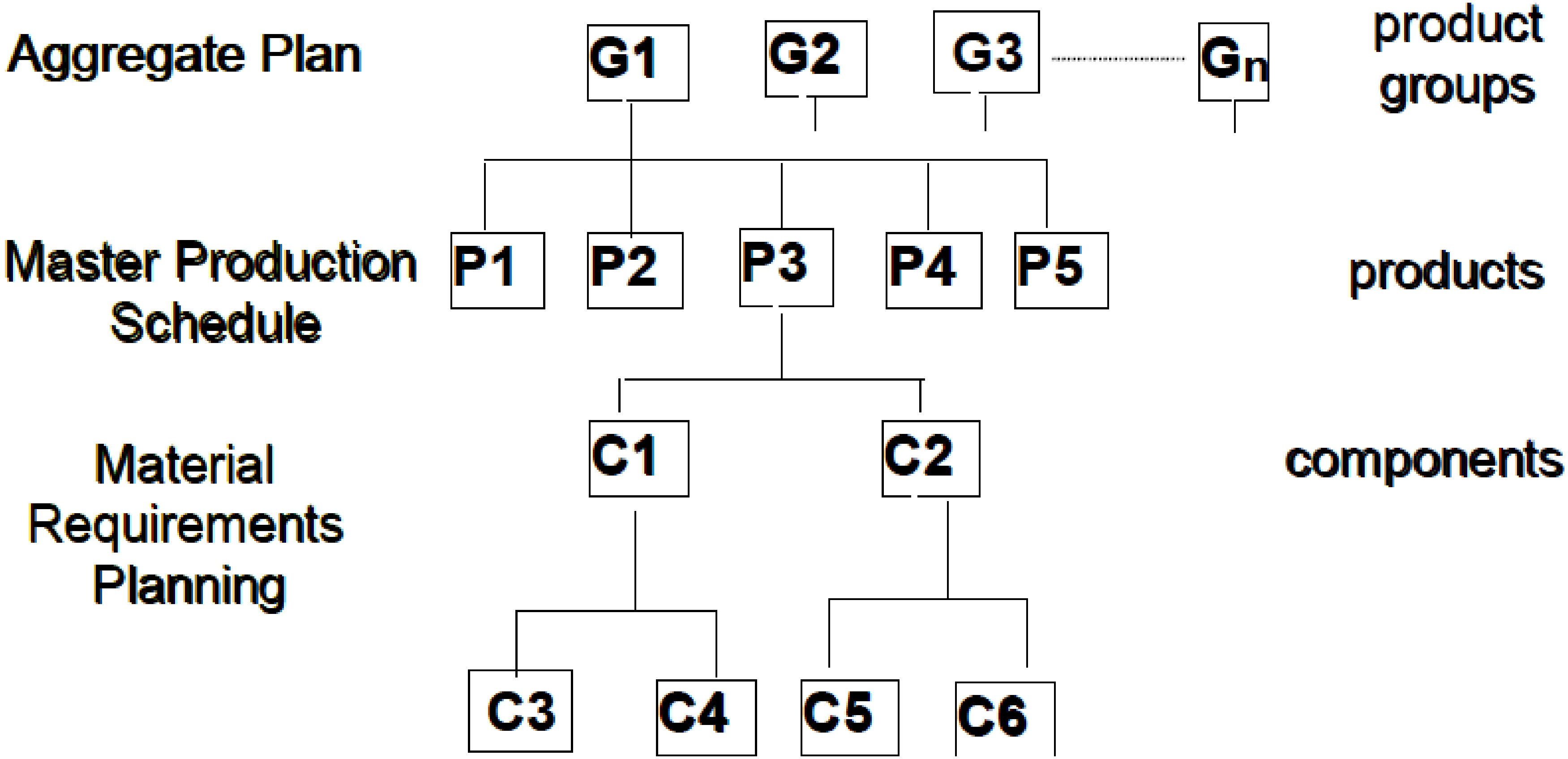


Top-Down Planning



- The planning performed in other MPC system modules is necessarily detailed, and the language is quite different from that required for production planning
- The production plan might be stated in rupees or aggregate units of output per month while the MPS could be in end product units per week
- MPS might be stated in units that use special bills of materials to manage complicated options

Planning Stages



Aggregate Planning Strategies

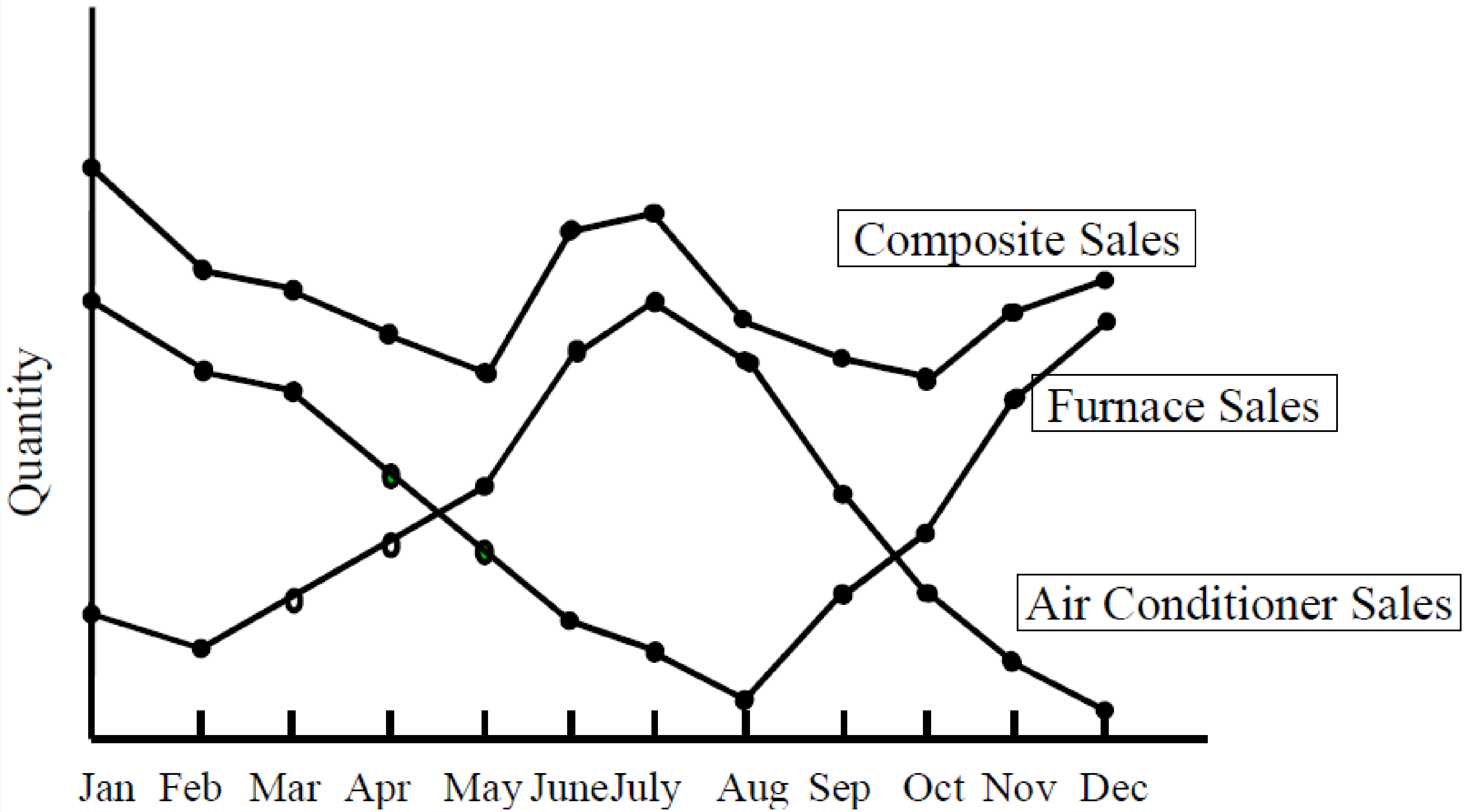
SUPPLY

- Workforce
  - hire / fire
  - overtime / slack
  - temporaries
  - extra shifts
- Inventory
- Subcontracting
- Product Mix

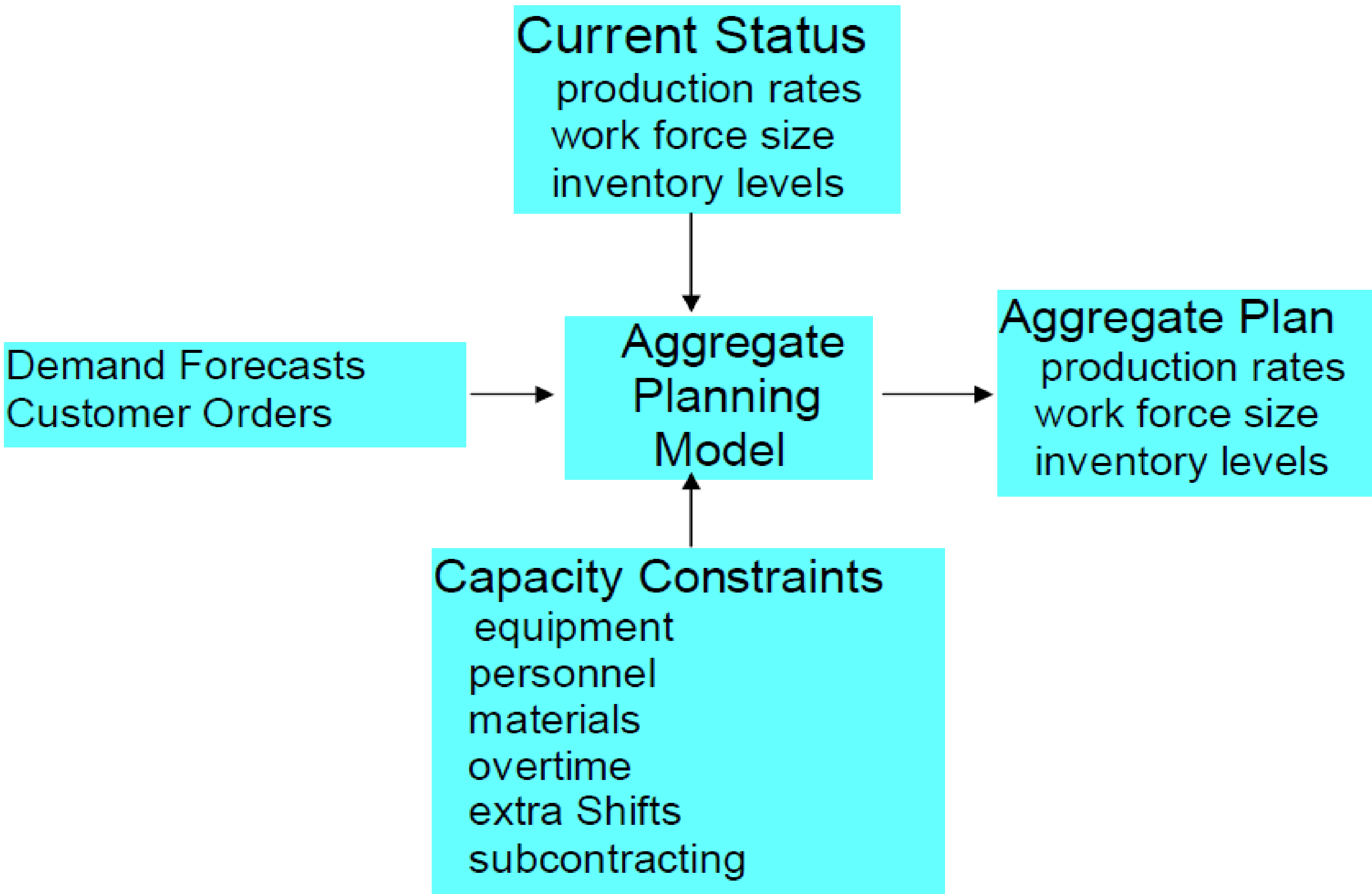
DEMAND

- Pricing
- Promotion
- Customer Service
- Backorders

Demand Effect: Contracyclical Products



Aggregate Planning Function



MANAGEMENT OPTIONS TO MEET FLUCTUATING DEMAND

- Build inventories in slack periods in anticipation of higher demands later in planning horizon.
- Carry backorders or tolerate lost sales during peak periods.
- Use over time in peak periods, under time in slack periods to vary output, while holding work force and facilities constant.
- Vary capacity by changing size of work force through hiring and firing.
- Vary capacity through changes in plant and equipment (generally long term option)
- Subcontracting may be resolved.

Each option involves cost (tangible or intangible). Aim in aggregate production planning is to choose best option.

KINDS OF COSTS INVOLVED

- Procurement Costs
- Production Costs
- Inventory holding Costs
- Shortage losses associated with backorders and lost sales
- Costs of increasing / decreasing work force
- Cost of overtime / under time
- Cost of changing production rates (Set ups, opportunity losses etc)

Period	Expected Demand	Cumulative Demand
1	100	100
2	180	280
3	220	500
4	150	650
5	100	950
6	200	950
7	250	1200
8	300	1500
9	260	1760
10	250	2010
11	240	2250
12	210	2460
13	140	2600

- Expected sales for one year planning horizon broken into 13 (4 week) periods.

ANALYSIS OF PLAN 1

Period	Production	Inventory	Back Order	Capacity change	Over time	Sub - contract
1	200	100	0	+20	0	0
2	200	120	0	0	0	0
3	200	100	0	0	0	0
4	200	150	0	0	0	0
5	200	250	0	0	0	0
6	200	250	0	0	0	0
7	200	200	0	0	0	0
8	200	100	0	0	0	0
9	200	40	0	0	0	0
10	200	0	10	0	0	0
11	200	0	50	0	0	0
12	200	0	60	0	0	0
13	200	0	0	0	0	0

ANALYSIS OF PLAN 2

Period	Production	Inventory	Back Order	Capacity change	Over time	Sub - contract
1	150	50	0	-30	0	0
2	150	20	0	0	0	0
3	150	0	50	0	0	0
4	150	0	50	0	0	0
5	150	0	0	0	0	0
6	250	50	0	+50	40	10
7	250	50	0	0	40	10
8	250	100	0	0	40	10
9	250	0	10	0	40	10
10	250	0	10	0	40	10
11	250	0				

HCP

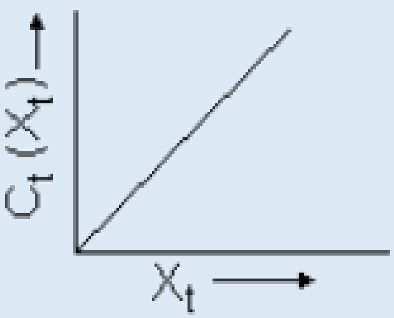
ASSUMPTIONS

All shortages backlogged

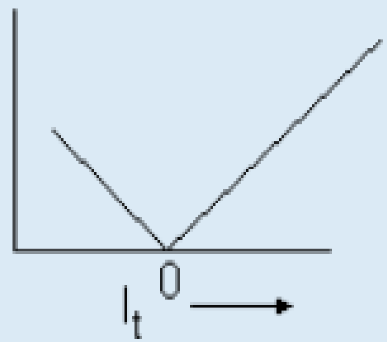
- Regular Time Capacity = 200 units/period
- Max. Overtime = 20% of Regular Time Capacity
- Overtime Preferable to Subcontract
- Assumed Initial Inventory = 0
- Initial Regular Time Prodn. Capacity = 180

NATURE OF COSTS AND SOLUTION PROCEDURES

Production Cost

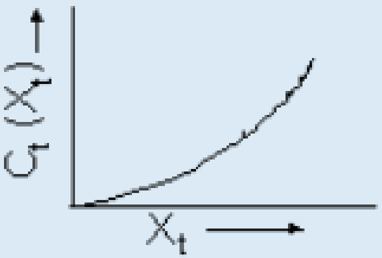
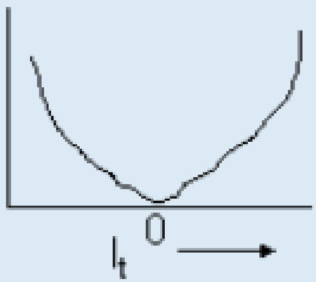


Inventory Cost



Linear Cost

- LP Simplified
- Transportation
- Transportation

Production Cost	Inventory Cost	Convex Cost
		Transportation (after piece wise linearization) HMMS (LDR) (quadratic cost)

Aggregate Production Planning Modelling Approaches

- **SOLUTION TECHNIQUES**
- Linear costs
  - Linear Programming
- Transportation Model
  - Piecewise linear and Convex costs
  - Holt, Modigliani, Muth and Simon's LDRs
  - Transportation Model
- Concave and Arbitrary Costs
  - Network based Model
- Non linear programming

LP : Definition of Variables

- r,v = cost /unit produced during regular time and overtime respectively
- Pt, Ot = units produced during regular time and overtime, respectively
- H,f = hiring and layoff costs per unit, respectively
- At, Rt = number of units increased or decreased, respectively, during consecutive periods
- C = inventory costs [per unit per period
- Dt = sales forecast
- Mt, Yt = Available regular time and overtime capacities respectively

Transportation Model

Period	1	2	3	4
Demands	100	105	200	95
Production capacity(units)				
Regular time	100	80	120	60
Overtime	40	40	50	30
Production Costs (Rs)				
Regular time	16	20	22	18
Overtime	24	30	30	26
Holding cost/unit/period (Rs)	2	2	4	5
Initial on hand inventory (units)	50 units			
Final desired inventory (units)	20 units			

Setting up the Transportation Problem

	D1	D2	D3	D4	Ifinal	Dummy	
Iin							50
R1							100
O1							40
R2							80
O2							40
R3							120
O3							50
R4							60
O4							30
	100	105	200	95	20	50	570

Introducing Unit Costs

	D1	D2	D3	D4	Ifinal	Dummy	
Iin	0	2	4	8	13	0	50
R1	16	18	20	24	29	0	100
O1	24	26	28	32	37	0	40
R2		20	22	26	31	0	80
O2		30	32	36	41	0	40
R3			22	26	31	0	120
O3			30	34	39	0	50
R4				18	23	0	60
O4				26	31	0	30
	100	105	200	95	20	50	570

Satisfying 1st Period Demand

	D1	D2	D3	D4	I_{final}	Dummy	
I_{in}	0 50	2	4	8	13	0	50 /0
R1	16 50	18	20	24	29	0	100/50
O1	24	26	28	32	37	0	40
R2		20	22	26	31	0	80
O2		30	32	36	41	0	40
R3			22	26	31	0	120
O3			30	34	39	0	50
R4				18	23	0	60
O4				26	31	0	30

Satisfying 2nd Period Demand

	D1	D2	D3	D4	I_{final}	Dummy	
I_{in}	0 50	2	4	8	13	0	50/0
R1	16 50	18 50	20	24	29	0	100/50/0
O1	24	26	28	32	37	0	40
R2		20 55	22	26	31	0	80/25
O2		30	32	36	41	0	40
R3			22	26	31	0	120
O3			30	34	39	0	50
R4				18	23	0	60
O4				26	31	0	30
	100	105	200	95	20	50	570

Satisfying 3rd Period Demand

	D1	D2	D3	D4	I_{final}	Dummy	
I_{in}	0 50	2	4	8	13	0	50/0
R1	16 50	18 50	20	24	29	0	100/50/0
O1	24	26	28 40	32	37	0	40/0
R2		20 55	22 25	26	31	0	80/25/0
O2		30	32	36	41	0	40
R3			22 120	26	31	0	120/0
O3			30 15	34	39	0	50/35
R4				18	23	0	60
O4				26	31	0	30
	100	105	200	95	20	50	570

Satisfying 4th Period Demand

	D1	D2	D3	D4	I final	Dummy	
I in	0 50	2	4	8	13	0	50/0
R1	16 50	18 50	20	24	29	0	100/50/0
O1	24	26	28 40	32	37	0	40/0
R2		20 55	22 25	26	31	0	80/25/0
O2		30	32	36	41	0	40
R3			22 120	26	31	0	120/0
O3			30 15	34 5	39	0	50/35/30
R4				18 60	23	0	60/0
O4				26 30	31	0	30/0
	100	105	200	95	20	50	570

Satisfying final inventory restrictions

	D 1	D 2	D 3	D 4	I_{final}	Dummy	
I_{in}	0 50	2	4	8	13	0	50/0
R 1	16 50	18 50	20	24	29	0	100/50/0
O 1	24	26	28 40	32	37	0	40/0
R 2		20 55	22 25	26	31	0	80/25/0
O 2		30	32	36	41	0	40
R 3			22 120	26	31	0	120/0
O 3			30 15	34 5	39 20	0	50/35/30/10
R 4				18 60	23	0	60/0
O 4				26 30	31	0	30/0
	100	105	200	95	20	50	570

Satisfying Dummy restrictions

	D 1	D 2	D 3	D 4	I_{final}	Dummy	
I_{in}	0 50	2	4	8	13	0	50/0
R 1	16 50	18 50	20	24	29	0	100/50/0
O 1	24	26	28 40	32	37	0	40/0
R 2		20 55	22 25	26	31	0	80/25/0
O 2		30	32	36	41	0 40	40/0
R 3			22 120	26	31	0	120/0
O 3			30 15	34 5	39 20	0 10	50/35/30/10/0
R 4				18 60	23	0	60/0
O 4				26 30	31	0	30/0
	100	105	200	95	20	50	570

Optimal Solution

- Total Cost of optimal solution
= Sum of (unit cost x quantity) = Rs 10370 for the planning horizon
- This includes
- the costs of production on regular and overtime and
- the costs of holding inventories

	Period 1	Period 2	Period 3	Period 4
Regular time production	100	80	120	60
Overtime production	40	------- -40	40 (-10)	30

Question 1

- Consider the data shown below for sales pattern of a popular brand of oil over the past 12 weeks.

Week	1	2	3	4	5	6	7	8	9	10	11	12
Sales (in '000) Litres	17	21	19	23	18	16	20	18	22	20	15	22

(a) Use 3-peroiod moving average to predict the forecast. Compute the forecast error.

(b) Use Exponential smoothening to forecast sales. (alpha = 0.2)

- (a) Moving average for (weeks 1-3)= (17+21+19)/3 = 19
  Moving average for (weeks 2-4)= (21+19+23)/3= 21
  Similarly the forecast for remaining weeks can be computed.

Week	1	2	3	4	5	6	7	8	9	10	11	12
Sales (in '000) Litres	17	21	19	23	18	16	20	18	22	20	15	22
Moving average Forecast				19	21	20	19	18	18	20	20	19
Forecast Error				23-19=4	18-21=-3	16-20=-4	20-19=1	18-18=0	22-18=4	20-20=0	15-20=-5	22-19=3
Square of Error				16	9	16	1	0	16	0	25	9

Sum of squared error = 92

Average sum of squared error = 92/9=10.22

- (b) Using Exponential smoothening method. Assume F2= 17
  F3= 0.2 Y2+ 0.8F2 = 0.2 x (21) +).8 x (17) = 17.8
  Once the actual; time series vale in week 3, Y3 = 19 is known, we can generate a forecast for week 4 as follows:
  F4= 0.2 Y3+ 0.8 F3= 0.2 x (19)+ 0.8 x (17.8) = 18.04
  By continuing in this manner we obtain the following table:

Week	1	2	3	4	5	6	7	8	9	10	11	12
Sales (in '000) Litres	17	21	19	23	18	16	20	18	22	20	15	22
Exponential Smoothening Forecast		17	17.8	18.04	19.03	18.83	18.26	18.61	18.49	19.19	19.35	18.48
Forecast Error		4	1.20	4.96	-1.03	-2.83	1.74	-0.61	3.51	0.81	-4.35	3.52
Square of Error		16	1.44	24.60	1.060	8.00	3.02	0.372	12.32	0.656	18.92	12.39

Sum of squared error = **98.778**

Average sum of squared error = 98.778/11=8.978 (which is less compared to Moving average method in (a)).

Question 2

- The sales data for a consumer item is shown below for year 2004.

Month	Sales (Rs in '000)
Jan	21.6
Feb	22.9
Mar	25.5
Apr	21.9
May	23.9
Jun	27.5
July	31.5
Aug	29.7
Sep	28.6
Oct	31.4

Using linear regression method, estimate the sales for the month of Nov.

HCP

- Let us indicate month as t and Sales in a month 't' as Yt
  Let us relabel months Jan to Oct as 1,2.. up to 10.
  The form of the regression equation is
  Yt = a + b t

T	Yt	tYt	t2
1	21.6	21.6	1
2	22.9	45.8	4
3	25.5	76.5	9
4	21.9	87.6	16
5	23.9	119.5	25
6	27.5	165.0	36
7	31.5	220.5	49
8	29.7	237.6	64
9	28.6	257.4	81
10	31.4	257.4	100
Totals			
55	264.5	1545.5	385

FUNCTIONS OF INVENTORIES

- Inventories are Idle Resources maintained in various forms:
  - Raw materials
  - Purchased & manufactured parts
  - Subassemblies
  - Finished products

  Since inventories represent a sizable investment in a logistic system, we must be aware of the functions they perform.

Five categories of stocks

- PIPELINE stock (in process stock, in transit stock)

  CYCLE stocks (batch production owing to
  - economies of scale
  - technological requirements)

  SEASONAL stocks (time varying requirements of an item)

  SAFETY stocks (supply and demand uncertainties,lead time uncertainties)

  Stocks held for OTHER REASONS (- decoupling stages of production - price, quantity discounts,- speculation)

INVENTORY RELATED COSTS

- Procurement cost
  Cost/order generally fixed (not dependent on order qty)

- Costs associated with existence of inventories
  (supply exceeds demand)
  Cost/unit/unit time
  i C (i = inventory carrying cost rate)

- Costs associated with stock outs
  (demand exceeds supply)(cost/unit) (cost/unit/unit time)

Procurement Costs

Procurement cost

Cost/order generally fixed

(not dependent on order qty)

- Administrative component
- Handling
- Transportation
- Inspection of arrivals

Cost of goods

Ordering cost

Inventory Holding Costs

- Costs associated with existence of inventories (supply exceeds demand)
  Cost/unit/unit time
  i C (i = inventory carrying cost rate)

  - Storage and handling
  - Interest on tied up capital
  - Property taxes
  - Insurance
  - Spoilage
  - Obsolescence
  - Pilferage

Shortage Cost

- Costs associated with stock outs (demand exceeds supply) (cost/unit) (cost/unit/unit time)
  - Additional costs of special order
  - Backorder, if possible
  - Loss of customer goodwill
  - Lost sales
  - Penalty costs

SELECTIVE INVENTORY CONTROL

In a large number there are

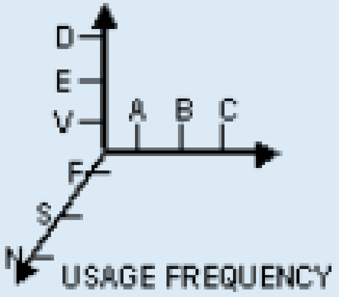
- significant few
- insignificant many

} PARETO's Law

Typical organisations deal with a large variety of stocked items
(10,000 – 100,000 … Is not uncommon)

Depending on rankings of

- VALUE (Σ(Annual demand X unit price)) ⇒ ABC Analysis (Always Better Control)
- CRITICALITY (Vital, Essential, Desirable) ⇒ VED Analysis
- USAGE FREQUENCY ⇒ FSN Analysis
  (Fast moving, Slow moving, Non moving)



Example-1

Month	Working Days	Demand (in units)	Month	Productive Days	Demand (in units)
Jan	22	8,000	July	22	26,000
Feb	19	12,000	Aug	11	16,000
Mar	21	18,000	Sept	21	18,000
Apr	22	20,000	Oct	22	14,000
May	21	28,000	Nov	18	9,000
June	21	25000	Dec	21	7,000

Additional Problem Information and Sample Values

- There are 100 employees on the payroll. Any change in employment must be accounted for in layoff or hiring costs.
- Productivity is 12 units per day per employee.
- Regular time salaries average $80 per day.
- Capacity can be increased up to an additional 30 percent through overtime.
- Units produced on overtime cost an additional $2 per unit.
- Units in inventory are charged at $2 per unit per month.
- Inventory shortages are charged at $10 per unit per month.
- Hiring and training an employee costs $300.
- Laying off an employee costs $200.
- Additional capacity is available through subcontracting at a cost of $8 per unit.
- The initial inventory level is 5,000 units.
- There should be 5,000 units in inventory at the end of the problem.
- Any units less than 5,000 in inventory at the end of the problem should be charged at the shortage cost charge.

The emphasis is on developing a plan which will yield the minimum possible total cost for next year's aggregate output.

Solution

A	B	C	D	E	F	G	H	I	J	K
Mon	Working Days	Number of Employees	Change in Employees	Regular Time Production	Forecast Demand	Starting Inventory	Net Additions to Inventory	End of Month Inventory	Monthly Average Inventory	Storage Cost ($2/Month)
Start						5000				
Jan	22	12	-88	3168	8000	5000	-4832	168	2584	2016
Feb	19	60	48	13680	12000	168	1680	1848	1008	2016
Mar	21	65	5	16380	18000	1848	-1620	228	1038	2076
Apr	22	76	11	20064	20000	228	64	292	260	50
May	21	110	34	27720	28000	292	-280	12	152	304
Jun	21	100	-10	25200	25000	12	200	212	112	224
Jul	22	100	0	26400	26000	212	400	612	412	824
Aug	11	117	17	15444	16000	612	-556	56	334	668
Sep	21	72	-45	18144	18000	56	144	200	128	256
Oct	22	53	-19	13992	14000	200	-8	192	196	392
Nov	18	45	-8	9720	9000	192	720	912	552	1104
Dec	21	45	0	11340	7000	912	4340	5252	3082	6164
---	------	---------	---------	---------	------	---------	---------	---------	---------	---------
TOT	241			201252	201000			9984		$19,716

L	M	N	O	P	Q	R	S	T	U
Monthly Labor Cost	Layoff Costs ($300/Layoff)	Hiring Costs ($200/hire)	Maximum Overtime Units	Overtime Units Built	Cost of Overtime Units	Number of Units Subcontracted	Cost of Units Subcontracted	Number of Units Short	Cost of Units Short
7920	17600	0	950	0	0	0	0	0	0
34200	0	14400	4104	0	0	0	0	0	0
40950	0	1500	4914	0	0	0	0	0	0
50160	0	3300	6019	0	0	0	0	0	0
69300	0	10200	8316	0	0	0	0	0	0
63000	2000	0	7560	0	0	0	0	0	0
66000	0	0	7920	0	0	0	0	0	0
38610	0	5100	4633	0	0	0	0	0	0
45360	9000	0	5443	0	0	0	0	0	0
34980	38000	0	4917	0	0	0	0	0	0
24300	1600	0	2916	0	0	0	0	0	0
28350	0	0	0	3402	0	0	0	0	0
-------	------------	-----------	--------	---------	---------	-------------	-------	-----	------
$503,130	$34,000	$34,500		0	0	0	0	0	0

Summary of Costs

Average Unit Cost	Total Cost	Minimum Possible Cost	Percent of Minimum Cost
$2.94	$591,348	$502,500	117.7%

- A - Month (given)
- B - Working Days (given)
- C - Number of Employees (Initial number is given, *then this is a decision to be made by the student*)
- D - Change in Employees (calculated difference in previous month) employment
- E - Regular Time Production (Number of Working Days [B] times Number of employees [C] times 12 [Units per Day per Employee])
- F - Forecast Demand (given)
- G - Starting inventory (Initial Condition, then previous month's ending value)
- H - Net Additions to Inventory (Starting inventory[G] +/- Regular Time Production[E])
- I - End of Month Inventory (Starting Inventory[G] +/- Net Additions to inventory [H] + any units produced on overtime [P] + any units subcontracted [R])
- J - Monthly Average Inventory (Sum of Starting Inventory [G] + End of Month Inventory [EI] divided by 2)
- K - Storage Cost (Monthly Average Inventory [J] times $2 per unit)
- L - Monthly Labor Cost (Number of Employees [C] times Working Days [B] times $30)
- M - Layoff Costs (If month-to-month employment has decreased then multiply the Absolute Value of the Change in Employees [D] times $300)
- N - Hiring Costs (If month-to-month employment has increased then multiply the Change in Employees [D] times $200)
- O - Maximum Overtime Units (30 % of Regular Time Production [E])
- P - Overtime Units Built (*This is a decision by the student*)
- Q - Cost of Overtime Units (Overtime Units Built P times $4.50 [Regular Time Unit Cost - $30/day divided by 12 units/day plus $2 additional cost/unit])
- R - Number of Units Subcontracted (*This is a decision by the student*)
- S - Cost of Units Subcontracted [Number of Units Subcontracted [R] times $8 [Cost per Subcontract Unit)
- T - Number of Units Short (If the End of Month Inventory is negative)
- U - Cost of Units Short this is the absolute value of the number of units short [I] times $10 [the default cost of any units short]

- Average Unit Cost - Total cost divided by number of units produced
- Total Cost - Summation of costs K, L, M, N, Q, S, and S
- Minimum Possible Cost - Forecast Demand [201,000] times Regular Time Unit Cost [$2.50]
- Percent of Minimum Cost - Calculation of the percentage the Total Cost represents of the Minimum Possible Cost

An examination of the costs shown for the problem reveals four independent costs:

- Regular production cost per unit is $2.50.
- Overtime production cost per unit is $4.50.
- Subcontract purchase cost per unit is $8.00.
- The default cost of shortages is $10.00 per unit.

HCP

Figure 1

Period		1	2	3	4	5	6
Forecast		100	150	300	300	500	150
Output							
	Regular	250	250	250	250	250	250
	Overtime						
	Subcontract						
Output-forecast		150	100	-50	-50	-250	100
Inventory							
	Beginning	0	150	250	200	150	0
	Ending	150	250	200	150	0	100
	Average	75	200	225	175	75	50
Backlog	0	0	0	0	0	100	0

Cost of aggregate plan utilizing a level strategy:

Output:						
Regular time	=	$ 5	X	1500	=	$7500
Overtime	=	$ 8	X	0	=	0
Subcontracted	=	$10	X	0	=	0
Inventory carrying cost	=	$ 3	X	850	=	2550
Backorders	=	$10	X	100	=	1000
Total Cost						$11050

Figure 2

Period		1	2	3	4	5	6
Forecast		100	150	300	300	500	150
Output							
	Regular	200	200	200	200	200	200
	Overtime				50	50	
	Subcontract					250	
Output-forecast		100	50	-100	-50	0	50
Inventory							
	Beginning	0	100	150	50	0	0
	Ending	100	150	50	0	0	50
	Average	50	125	100	25	0	25
Backlog	0	0	0	0	0	0	0

Output:

Regular time	= $ 5	X	1200	=	$6000
Overtime	= $ 8	X	100	=	800
Subcontracted	= $12	X	250	=	3000
Inventory carrying cost	= $ 3	X	325	=	975
Backorders	= $10	X	0	=	0

Total Cost $10775

JC Company p. 292

- Materials Cost: $100/unit
- Labor: 5 hours per unit, $4/hr RT, $6/hr OT
  - Subcontract $20/unit ($120 - $100 matl savings)
  - Holding cost $1.5/unit/mo
  - Stockout cost $5/unit/mo
  - Hiring cost $200
  - Firing cost $250
  - Starting inventory 400 units, safety stock 25%

	Jan	Feb	Mar	Apr	May	June
Demand Forecast	1,800	1,500	1,100	900	1,100	1,600

Exhibit 11.3

- Goal of 25% of sales as "safety stock"
- For planning, assume safety stock never used

	Jan	Feb	Mar	Apr	May	June
Beginning Inventory	400	450	375	275	225	275
Demand Forecast	1,800	1,500	1,100	900	1,100	1,600
Safety Stock (0.25*demand foreast)	450	375	275	225	275	400
Production Requirement (Forecast+SS-Begin Inv)	1,850	1,425	1,000	850	1,150	1,725
Ending Inventory	450	375	275	225	275	400

Hire and Fire, no OT: Plan 1

	Jan	Feb	Mar	Apr	May	June
Production Requirement (Forecast+SS-Begin Inv)	1,850	1,425	1,000	850	1,150	1,725
Hours needed	9,250	7,125	5,000	4,250	5,750	8,625
Days per month	22	19	21	21	22	20
Hrs/mo/worker	176	152	168	168	176	160
Workers needed	53	47	30	25	33	54
Workers hired	0	0	0	0	8	21
Workers Laid off	0	6	17	5	0	0
Production Labor Cost	$ 37,000	$ 28,500	$ 20,000	$ 17,000	$ 23,000	$ 34,500
Hiring Cost	$ -	$ -	$ -	$ -	$ 1,600	$ 4,200
Firing Cost	$ -	$ 1,500	$ 4,250	$ 1,250	$ -	$ -

Labor cost =	$ 160,000
Hiring Cost =	$ 5,800
Firing Cost =	$ 7,000
Total	**$ 172,800**

- Start with workers needed for month 1
- May have too many at end

Constant Workforce: Plan 2

	Jan	Feb	Mar	Apr	May	June
Starting Inv	400	8	(276)	(32)	412	720
Production Req	1,850	1,425	1,000	850	1,150	1,725
Work Days	22	19	21	21	22	20
Work Hours	7,040	6,080	6,720	6,720	7,040	6,400
Actual Production	1,408	1,216	1,344	1,344	1,408	1,280
Demand Forecast	1,800	1,500	1,100	900	1,100	1,600
Ending Inventory	8	(276)	(32)	412	720	400
Shortage Cost	-	1,380	160	-	-	-
Safety Stock	450	375	275	225	275	400
Excess Inventory	-	-	-	187	445	-
Holding Cost	-	-	-	281	668	-

Labor Cost	$ 160,000
Holding Cost	$ 948
Shortage Cost	$ 1,540
	$ 162,488

- Total D = 8,000 units
- 5*8,000 = 40,000 hours
- 125 days total = 1,000 hrs
- 40,000/1,000 = 40 workers
- No penalty missing safety stock

Subcontract: Plan 3

	Jan	Feb	Mar	Apr	May	June
Production Req.	1,850	1,425	1,000	850	1,150	1,725
Work Days	22	19	21	21	22	20
Work Hrs	4,400	3,800	4,200	4,200	4,400	4,000
Actual production	880	760	840	840	880	800
Subcontracted	970	665	160	10	270	925
Subcontr. Cost	$ 19,400	$13,300	$ 3,200	$ 200	$ 5,400	$18,500
Labor Cost	$ 17,600	$15,200	$16,800	$16,800	$17,600	$16,000

Workers =	25
Subcontr. Cost =	$ 60,000
Labor Cost =	$ 100,000
Total Cost =	$ 160,000

- April has lowest demand
- 21 days * 8 hrs = 168
- 850*5/168 = 25.3 workers
- Subcontract rest

Constant Workers with OT: 4

# workers	38					
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**
Work Days	22	19	21	21	22	20
Work Hrs	6,688	5,776	6,384	6,384	6,688	6,080
Reg. Production	1,338	1,155	1,277	1,277	1,338	1,216
Dem Forecast	1,800	1,500	1,100	900	1,100	1,600
Starting Inv	400	-	-	177	554	792
Net Inv before OT	(62)	(345)	177	554	792	408
Units OT	62	345	-	-	-	-
Ending Inv	-	-	177	554	792	408
Safety Stock	450	375	275	225	275	400
Excess Inv	-	-	-	329	517	8
Holding Cost	$ -	$ -	$ -	$ 494	$ 776	$ 12
OT Cost	$ 1,860	$10,350	$ -	$ -	$ -	$ -
RT Cost	$ 26,752	$23,104	$25,536	$25,536	$26,752	$24,320
Holding Cost =	$ 1,281					
OT Cost =	$ 12,210					
RT Cost =	$ 152,000					
	$165,491					

- Find # workers to do all except biggest mos in RT
- Trial and error
- Not enough safety stock

Aggregate Planning Examples: Unit Demand and Cost Data

Suppose we have the following unit demand and cost information:

Demand/mo	Jan	Feb	Mar	Apr	May	Jun
	4500	5500	7000	10000	8000	6000

Materials	$5/unit
Holding costs	$1/unit per mo.
Marginal cost of stock-out	$1.25/unit per mo.
Hiring and training cost	$200/worker
Layoff costs	$250/worker
Labor hours required	.15 hrs/unit
Straight time labor cost	$8/hour
Beginning inventory	250 units
Productive hours/worker/day	7.25
Paid straight hrs/day	8

Cut-and-Try Example: Determining Straight Labor Costs and Output

Given the demand and cost information below, what are the aggregate hours/worker/month, units/worker, and dollars/worker?

Demand/mo	Jan	Feb	Mar	Apr	May	Jun
	4500	5500	7000	10000	8000	6000

Productive hours/worker/day 7.25

Paid straight hrs/day 8

	Jan	Feb	Mar	Apr	May	Jun
Days/mo	22	19	21	21	22	20
Hrs/worker/mo						
Units/worker						
$/worker						

Cut-and-Try Example: Determining Straight Labor Costs and Output

Given the demand and cost information below, what are the aggregate hours/worker/month, units/worker, and dollars/worker?

Demand/mo	Jan	Feb	Mar	Apr	May	Jun
	4500	5500	7000	10000	8000	6000

7.25x22

Productive hours/worker/day 7.25

Paid straight hrs/day 8

7.25/0.15=48.33 &
48.33x22=1063.33

22x8hrsx$8=$1408

	Jan	Feb	Mar	Apr	May	Jun
Days/mo	22	19	21	21	22	20
Hrs/worker/mo	159.5	137.75	152.25	152.25	159.5	145
Units/worker	1063.33	918.33	1015	1015	1063.33	966.67
$/worker	$1,408	1,216	1,344	1,344	1,408	1,280

Chase Strategy
(Hiring & Firing to meet demand)

	Jan
Days/mo	22
Hrs/worker/mo	159.5
Units/worker	1,063.33
$/worker	$1,408
	Jan
Demand	4,500
Beg. inv.	250
Net req.	
Req. workers	
Hired	
Fired	
Workforce	
Ending inventory	0

Lets assume our current workforce is 7 workers.

First, calculate net requirements for production, or Demand-Begin Inv.

Then, calculate number of workers needed to produce the net requirements, or Net req/Units per worker or # workers

Finally, determine the number of workers to hire/fire. Current Workers-Required = (-) hire or (+) fire

Chase Strategy
(Hiring & Firing to meet demand)

	Jan
Days/mo	22
Hrs/worker/mo	159.5
Units/worker	1,063.33
$/worker	$1,408
	Jan
Demand	4,500
Beg. inv.	250
Net req.	4,250
Req. workers	3.997
Hired	
Fired	3
Workforce	4
Ending inventory	0

Lets assume our current workforce is 7 workers.

First, calculate net requirements for production, or 4500-250=4250 units

Then, calculate number of workers needed to produce the net requirements, or 4250/1063.33=3.997 or 4 workers **Round-up

Finally, determine the number of workers to hire/fire. In this case we only need 4 workers, we have 7, so 3 can be fired.

Below are the complete calculations for the remaining months in the six month planning horizon.

	Jan	Feb	Mar	Apr	May	Jun
Days/mo	22	19	21	21	22	20
Hrs/worker/mo	159.5	137.75	152.25	152.25	159.5	145
Units/worker	1,063	918	1,015	1,015	1,063	967
$/worker	$1,408	1,216	1,344	1,344	1,408	1,280
	Jan	Feb	Mar	Apr	May	Jun
Demand	4,500	5,500	7,000	10,000	8,000	6,000
Beg. inv.	250					
Net req.	4,250	5,500	7,000	10,000	8,000	6,000
Req. workers	3.997	5.989	6.897	9.852	7.524	6.207
Hired		2	1	3		
Fired	3				2	1
Workforce	4	6	7	10	8	7
Ending inventory	0	0	0	0	0	0

Below are the complete calculations for the remaining months in the six month planning horizon with the other costs included.

	Jan	Feb	Mar	Apr	May	Jun	
Demand	4,500	5,500	7,000	10,000	8,000	6,000	
Beg. inv.	250						
Net req.	4,250	5,500	7,000	10,000	8,000	6,000	
Req. workers	3.997	5.989	6.897	9.852	7.524	6.207	
Hired		2	1	3			
Fired	3				2	1	
Workforce	4	6	7	10	8	7	
Ending inventory	0	0	0	0	0	0	
	Jan	Feb	Mar	Apr	May	Jun	Costs
Material	$21,250.00	$27,500.00	$35,000.00	$50,000.00	$40,000.00	$30,000.00	203,750.00
Labor	5,627.59	7,282.76	9,268.97	13,241.38	10,593.10	7,944.83	53,958.62
Hiring cost		400.00	200.00	600.00			1,200.00
Firing cost	750.00				500.00	250.00	1,500.00
							$260,408.62

Level Workforce Strategy (Surplus and Shortage Allowed)

Lets take the same problem as before but this time use the Level Workforce strategy.

This time we will seek to use a workforce level of 6 workers.

	Jan
Demand	4,500
Beg. inv.	250
Net req.	4,250
Workers	6
Production	6,380
Ending inventory	2,130
Surplus	2,130
Shortage	

Below are the complete calculations for the remaining months in the six month planning horizon.

	Jan	Feb	Mar	Apr	May	Jun
Demand	4,500	5,500	7,000	10,000	8,000	6,000
Beg. inv.	250	2,130	2,140	1,230	-2,680	-1,300
Net req.	4,250	3,370	4,860	8,770	10,680	7,300
Workers	6	6	6	6	6	6
Production	6,380	5,510	6,090	6,090	6,380	5,800
Ending inventory	2,130	2,140	1,230	-2,680	-1,300	-1,500
Surplus	2,130	2,140	1,230			
Shortage				2,680	1,300	1,500

Note, if we recalculate this sheet with 7 workers we would have a surplus.

Below are the complete calculations for the remaining months in the six month planning horizon with the other costs included.

Jan	Feb	Mar	Apr	May	Jun		
4,500	5,500	7,000	10,000	8,000	6,000		
250	2,130	10	-910	-3,910	-1,620		
4,250	3,370	4,860	8,770	10,680	7,300		
6	6	6	6	6	6		
6,380	5,510	6,090	6,090	6,380	5,800		
2,130	2,140	1,230	-2,680	-1,300	-1,500		
2,130	2,140	1,230					
			2,680	1,300	1,500		
Jan	Feb	Mar	Apr	May	Jun		
$8,448	$7,296	$8,064	$8,064	$8,448	$7,680	$48,000.00	Labor
31,900	27,550	30,450	30,450	31,900	29,000	181,250.00	Material
2,130	2,140	1,230				5,500.00	Storage
			3,350	1,625	1,875	6,850.00	Stock-out
						$241,600.00	

Note, the total costs under this strategy are less than under Chase.

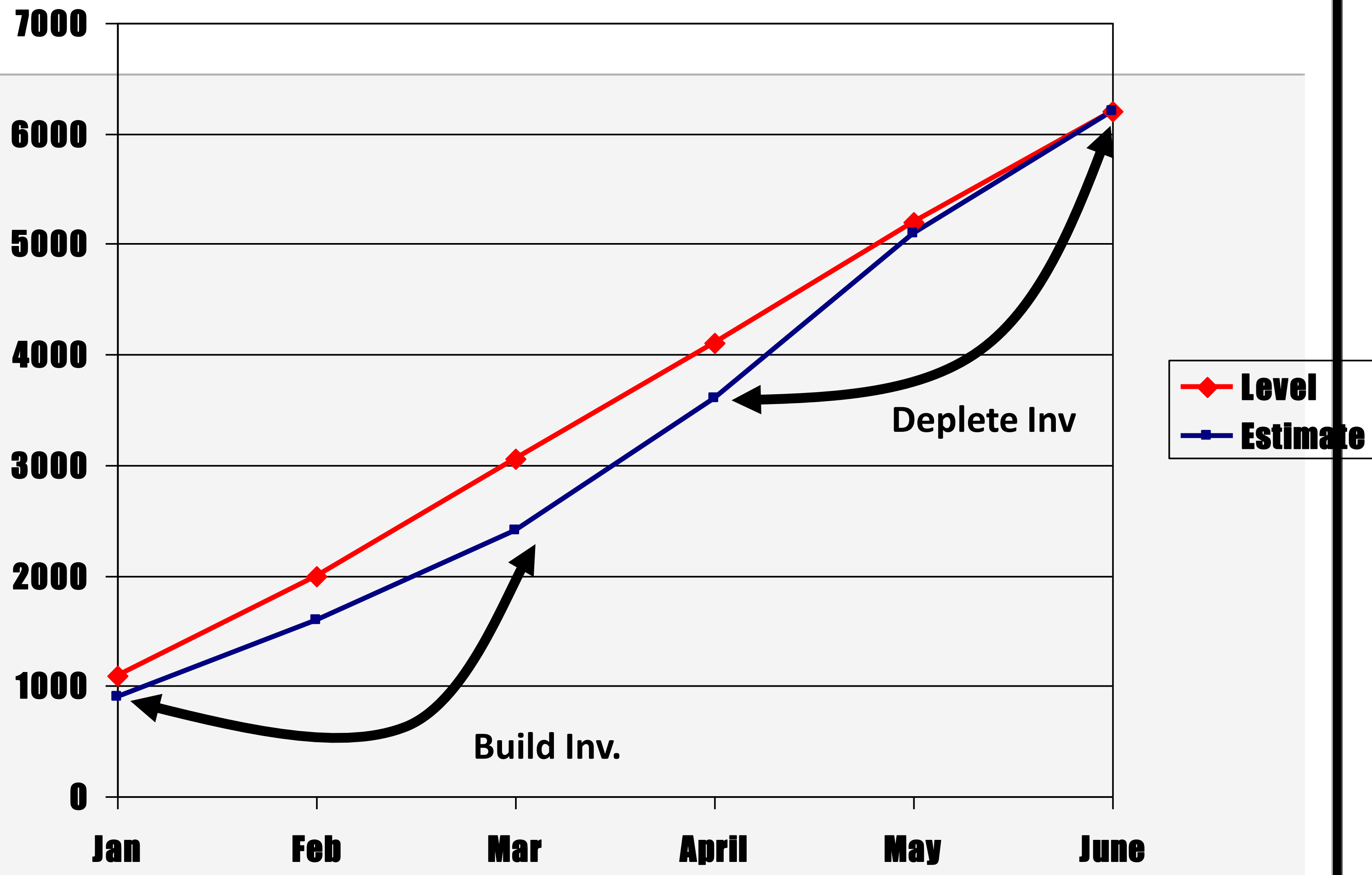
Graphical Methods

Month	Expected Demand	Production Days	Demand per Day
Jan	900	22	41
Feb	700	18	39
Mar	800	21	38
Apr	1200	21	58
May	1500	22	68
June	1100	20	55
	6200	124	

Level = 6200/124= 50 units/day

Month	Estimated Demand/ Month	Level Production	Difference Build vs. Deplete Inv
Jan	900	1100	+200
Feb	700	900	+200
Mar	800	1050	+250
Apr	1200	1050	-150
May	1500	1100	-400
June	1100	1000	-100

Level demand: plotted cumulatively



Aggregate Planning: Example

(Adapted from Chase and Aquilano,
"Fundamentals of Operations Management",
Irwin Pub., 1991)

Example: Introduction

A vacuum cleaner manufacturer tries to "plan ahead" in order to effectively address the seasonal variation appearing in the annual demand of its products. A planning horizon of 6 months is used. The (aggregate) demand forecast for the next six months along the number of working days are as follows:

Month	Demand Forecast	No. of Working Days
Jan.	1,800	22
Febr.	1,500	19
March	1,100	21
April	900	21
May	1,100	22
June	1,600	20
	Total: 8,000 units	Total: 125 Days

Example: Introduction (cont.)

The associated cost break-down is as follows:

Cost Item	Cost($)
Material	$100 per unit
Inventory Holding	$5 per unit per month
Marginal Stockout	$10 per unit per month
Marginal Cost of Subcontracting	$20 per unit
(Cost of buying less material costs)	
Hiring and Training	$1000 per worker
Layoff	$1500 per worker
Regular Labor cost per hour	$15 per employee per hour
Overtime labor cost per hour	$20 per employee per hour

Example: Introduction (cont.)

Starting and Operating Conditions:

Current Inventory	400 units
Current Workforce	38 workers
Labor hours per unit	5 employee-hours/unit
Regular labor time per employee per day	8 hours
Inventory at the end of each month	25% of coresp. demand

The tabular approach: Computing net requirements

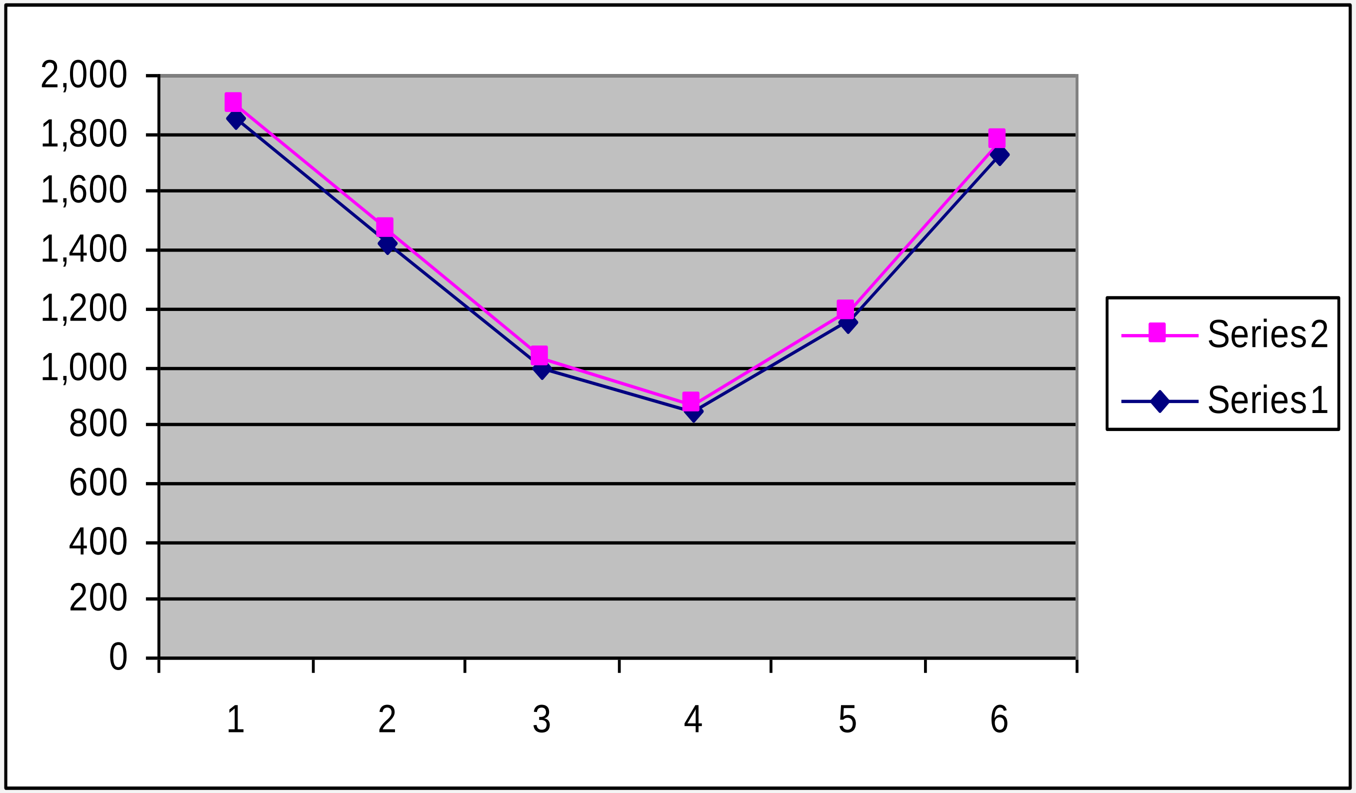
Month	Beg. Inv.	Forc. Dem.	End. Inv.	Prod. Req.
Jan.	400	1,800	450	1,850
Febr.	450	1,500	375	1,425
March	375	1,100	275	1,000
April	275	900	225	850
May	225	1,100	275	1,150
June	275	1,600	400	1,725
				8,000

Plan 1: Demand Chasing

Produce exactly the quantities required for each period through regular labor, by varying the workforce size.

Month	Prod. Req.	Req. Labor Hours	Work Days	Workers	PC	WC	HC	FC
Jan.	1,850	9,250	22	53	185000	139920	15000	0
Febr.	1,425	7,125	19	47	142500	107160	0	9000
March	1,000	5,000	21	30	100000	75600	0	25500
April	850	4,250	21	25	85000	63000	0	7500
May	1,150	5,750	22	33	115000	87120	8000	0
June	1,725	8,625	20	54	172500	129600	21000	0
					800000	602400	44000	42000
							TC=	1488400

Plan 1: Demand Chasing (cont.)



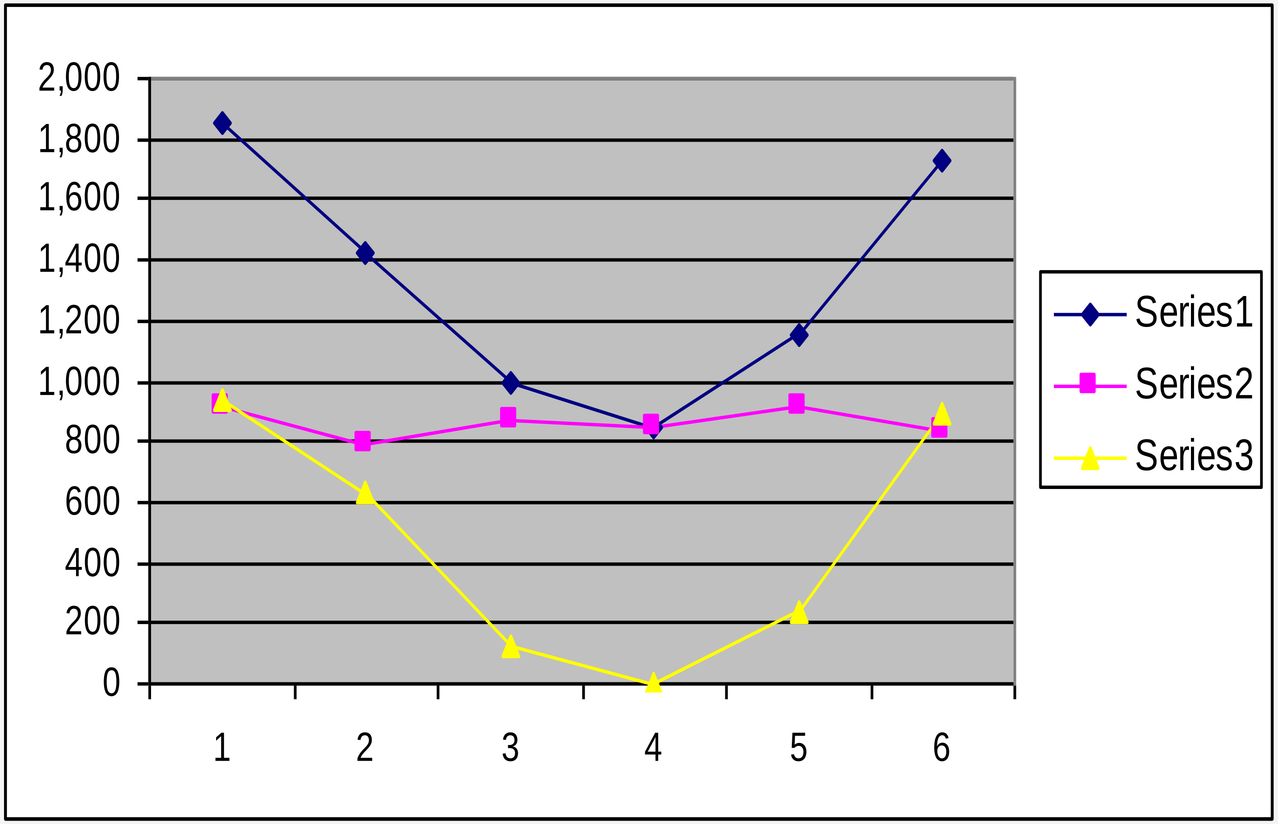
Plan 2: Minimum Production Workforce + Subcontracting

- Adjust the workforce so that the minimal monthly demand is met through regular labor.
- Subcontract all excess demand.

Month	Prod. Req.	Req. Labor Hours	Work Days	Workers	Int. Prod.	Subcontr. Quantity	PC	WC	SC	FC
Jan.	1,850	9,250	22	26	915	935	91500	68640	112200	18000
Febr.	1,425	7,125	19	26	790	635	79000	59280	76200	0
March	1,000	5,000	21	26	874	126	87400	65520	15120	0
April	850	4,250	21	26	850	0	85000	65520	0	0
May	1,150	5,750	22	26	915	235	91500	68640	28200	0
June	1,725	8,625	20	26	832	893	83200	62400	107160	0
							517600	390000	338880	18000
									TC=	1264480

HCP

Plan 2: Minimum Production Workforce + Subcontracting

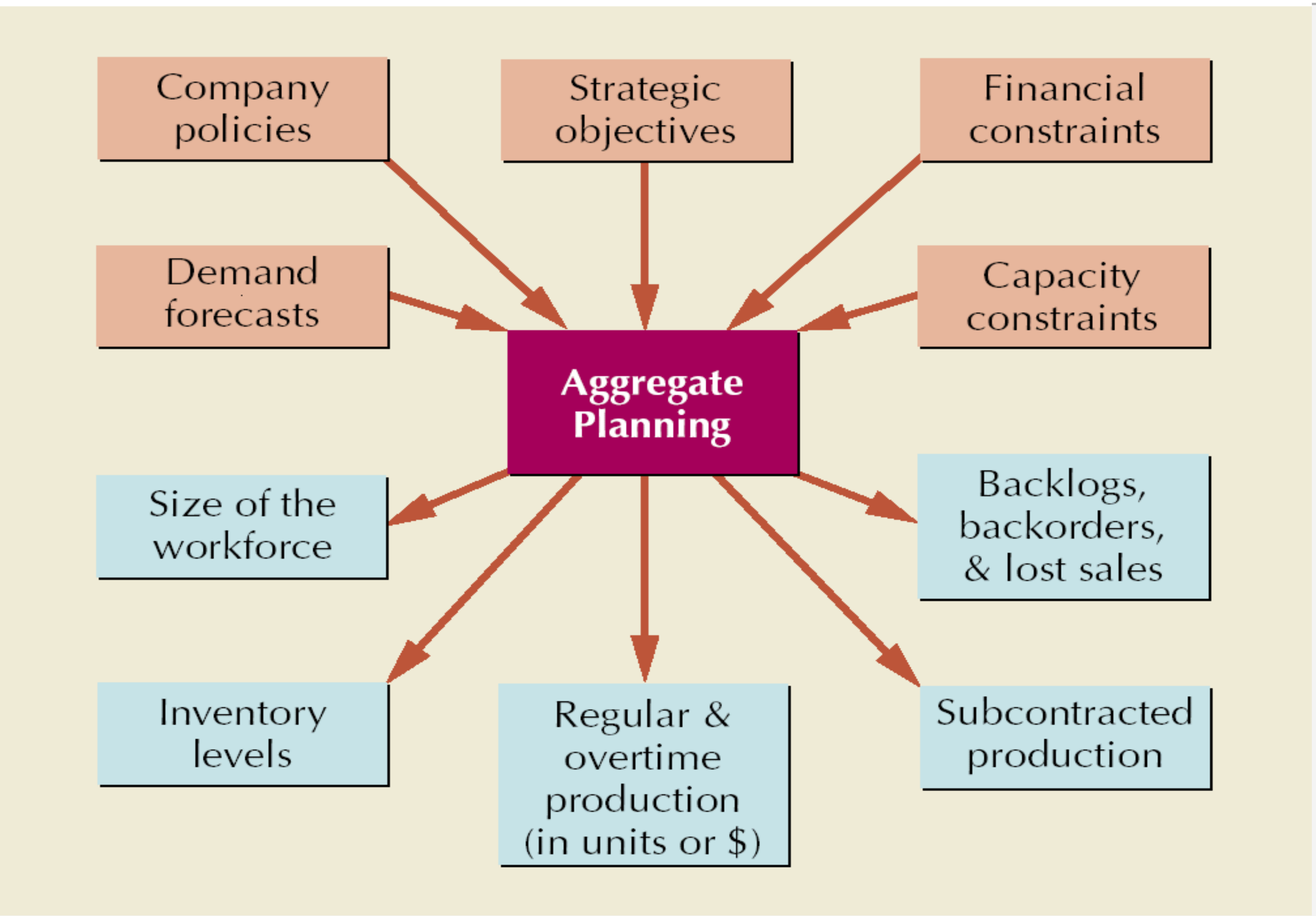


Plan 3: Anticipatory (Seasonal) Inventories + Backlogging

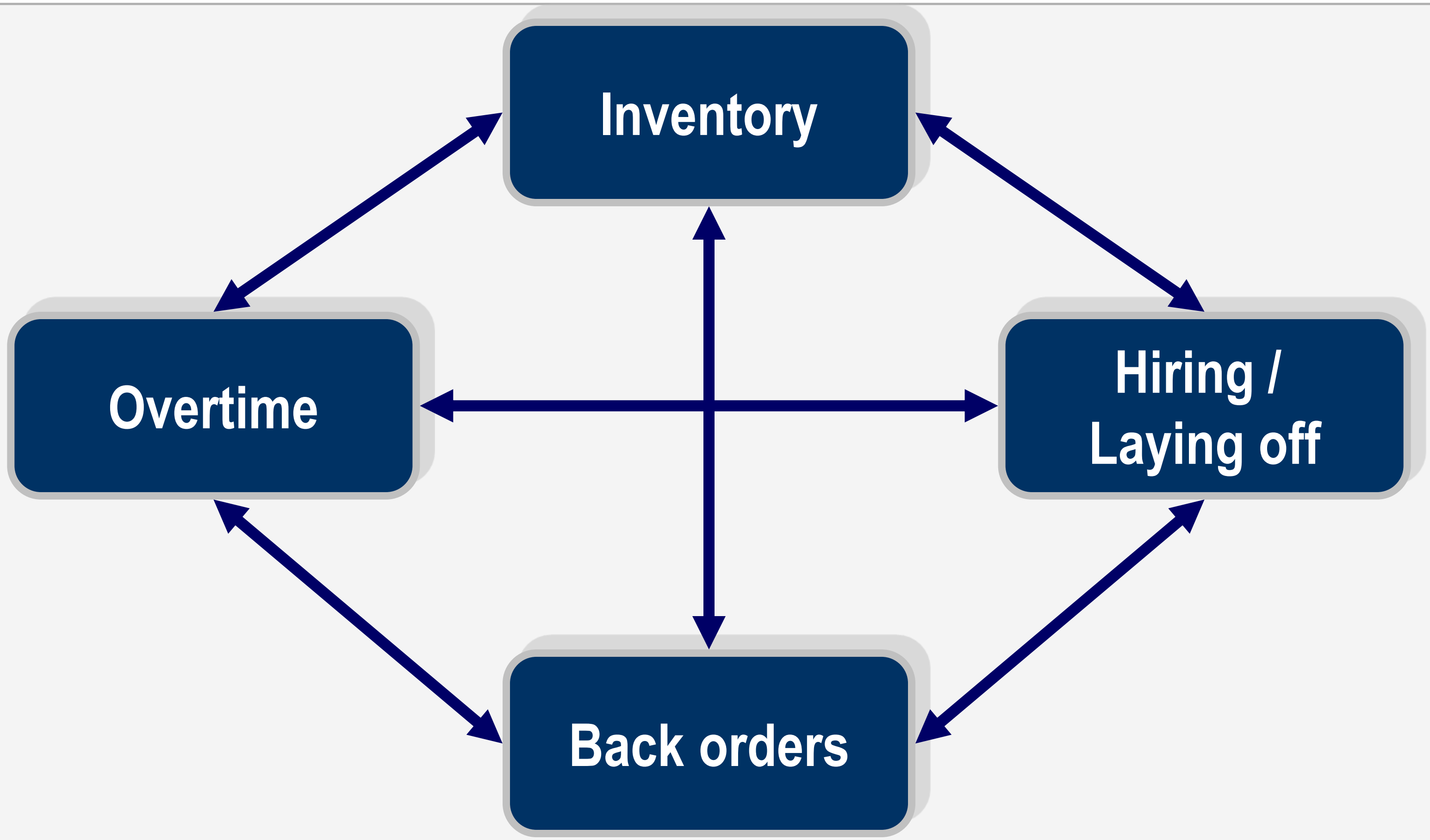
- Employ the minimal workforce level that can cover the total production requirements over the considered planning horizon, by working only regular hours.
- Take care of the demand fluctuations by building anticipatory inventories and/or backlogging excess demand.

Month	Prod. Req.	Work Days	Workers	Act. Prod.	Inventory	Backlogs	PC	WC	IC	BC
Jan.	1,800	22	38	1338	0	62	133800	100320	0	620
Febr.	1,500	19	38	1155	0	407	115500	86640	0	4070
March	1,100	21	38	1277	0	230	127700	95760	0	2300
April	900	21	38	1277	147	0	127700	95760	735	0
May	1,100	22	38	1338	385	0	133800	100320	1925	0
June	1,600	20	38	1215	0	0	121500	91200	0	0
	8000	125		7600			760000	570000	2660	6990
									TC=	1339650

Aggregate Planning Process



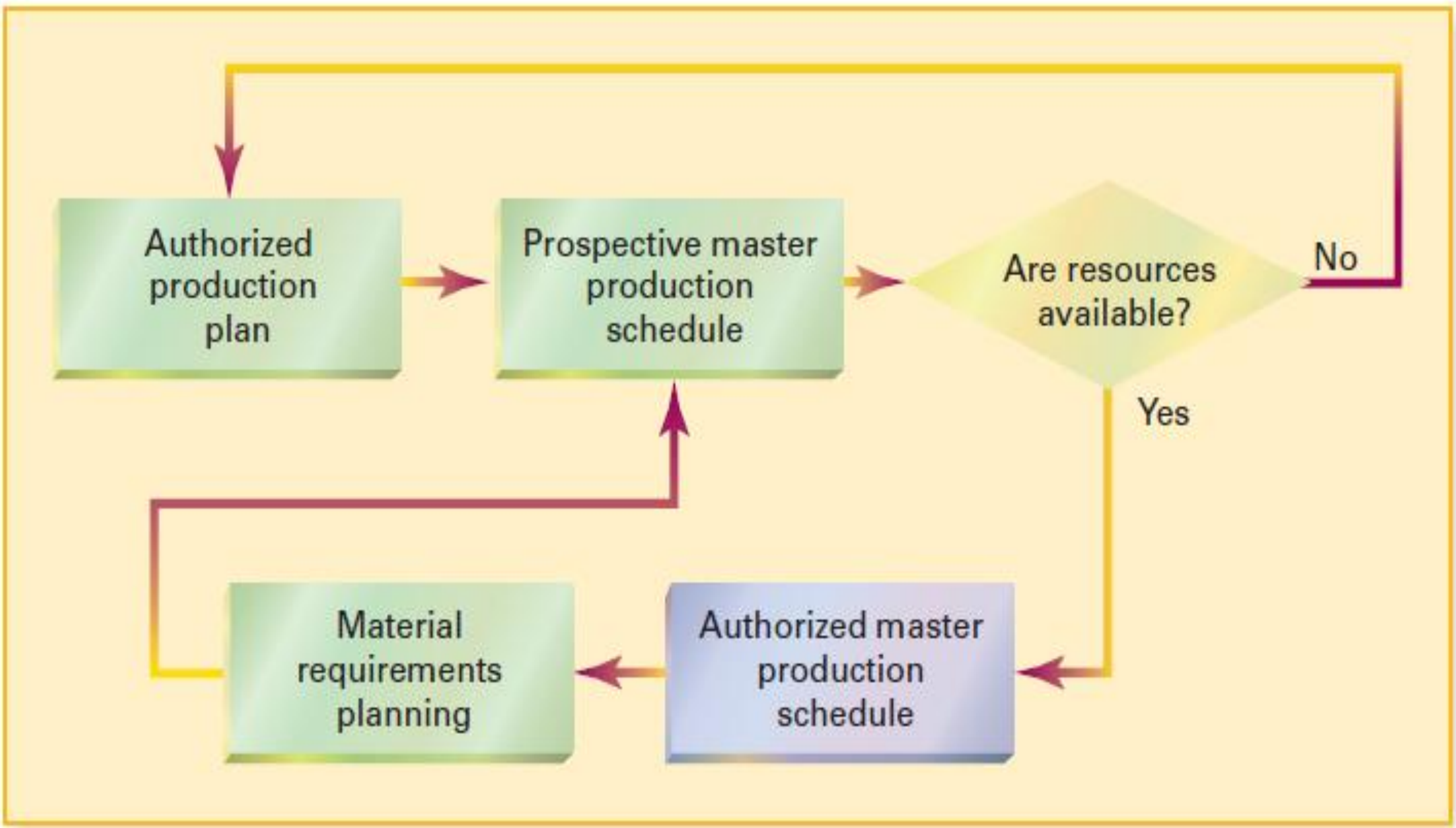
Trade off analysis



Master Production Scheduling

- Develop an MPS in a make-to-stock environment.
- compute available-to-promise quantities for end items.
- The master production schedule (MPS) is a link between the firm's broad strategies and strategic plans that enables the firm to achieve its goals.
- The MPS provides essential information for functional areas such as **operations, marketing, and finance**.
- In this supplement, we discuss the master production scheduling process, the need for functional coordination, the way to develop an MPS, the information that an MPS provides to assist in **negotiating delivery dates**, and the managerial considerations for establishing and stabilizing the MPS.

Master Production Scheduling Process



DEVELOPING A MASTER PRODUCTION SCHEDULE

- The process of developing a master production schedule includes
- (1) calculating the projected on-hand inventory
- (2) determining the timing and size of the production quantities of specific products.

- ***Step 1. Calculate Projected On-Hand Inventories***
- The first step is to calculate the projected on-hand inventory, which is an estimate of the amount of inventory available each week after demand has been satisfied:

$$\begin{pmatrix}\text{Projected on-hand}\\ \text{inventory at the end}\\ \text{of this week}\end{pmatrix} = \begin{pmatrix}\text{On-hand}\\ \text{inventory at the}\\ \text{end of last week}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\ \text{due at the start}\\ \text{of this week}\end{pmatrix} - \begin{pmatrix}\text{Projected}\\ \text{requirements}\\ \text{this week}\end{pmatrix}$$

$$\text{Inventory} = \begin{pmatrix}\text{55 chairs}\\ \text{currently}\\ \text{in stock}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\ \text{(0 for week 1)}\end{pmatrix} - \begin{pmatrix}\text{38 chairs already}\\ \text{promised for}\\ \text{delivery in week 1}\end{pmatrix} = 17 \text{ chairs}$$

Item: Ladder-back chair

Quantity on Hand: 55	April	
	1	2
Forecast	30	30
Customer orders (booked)	38	27
Projected on-hand inventory	17	–13
MPS quantity	0	0
MPS start		

Explanation:
Forecast is less than booked orders in week 1; projected on-hand inventory balance = 55 + 0 – 38 = 17.

Explanation:
Forecast exceeds booked orders in week 2; projected on-hand inventory balance = 17 + 0 – 30 = –13. The shortage signals a need to schedule an MPS quantity for completion in week 2.

Step 2. Determine the Timing and Size of MPS Quantities.

- The goal of determining the timing and size of MPS quantities is to maintain a nonnegative projected on-hand inventory balance.
- As shortages in inventory are detected, MPS quantities should be scheduled to cover them, much as planned receipts are scheduled in an MRP record

$$\text{Inventory} = \begin{pmatrix}\text{17 chairs in} \\ \text{inventory at the} \\ \text{end of week 1}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity} \\ \text{of 150 chairs}\end{pmatrix} - \begin{pmatrix}\text{Forecast of} \\ \text{30 chairs}\end{pmatrix} = 137 \text{ chairs}$$

Item: Ladder-back chair | **Order Policy: 150 units**
Lead Time: 1 week

Quantity on Hand: 55	April				May			
	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	35	35	35	35
Customer orders (booked)	38	27	24	8	0	0	0	0
Projected on-hand inventory	17	137	107	77	42	7	122	87
MPS quantity	0	150	0	0	0	0	150	0
MPS start	150	0	0	0	0	150	0	0

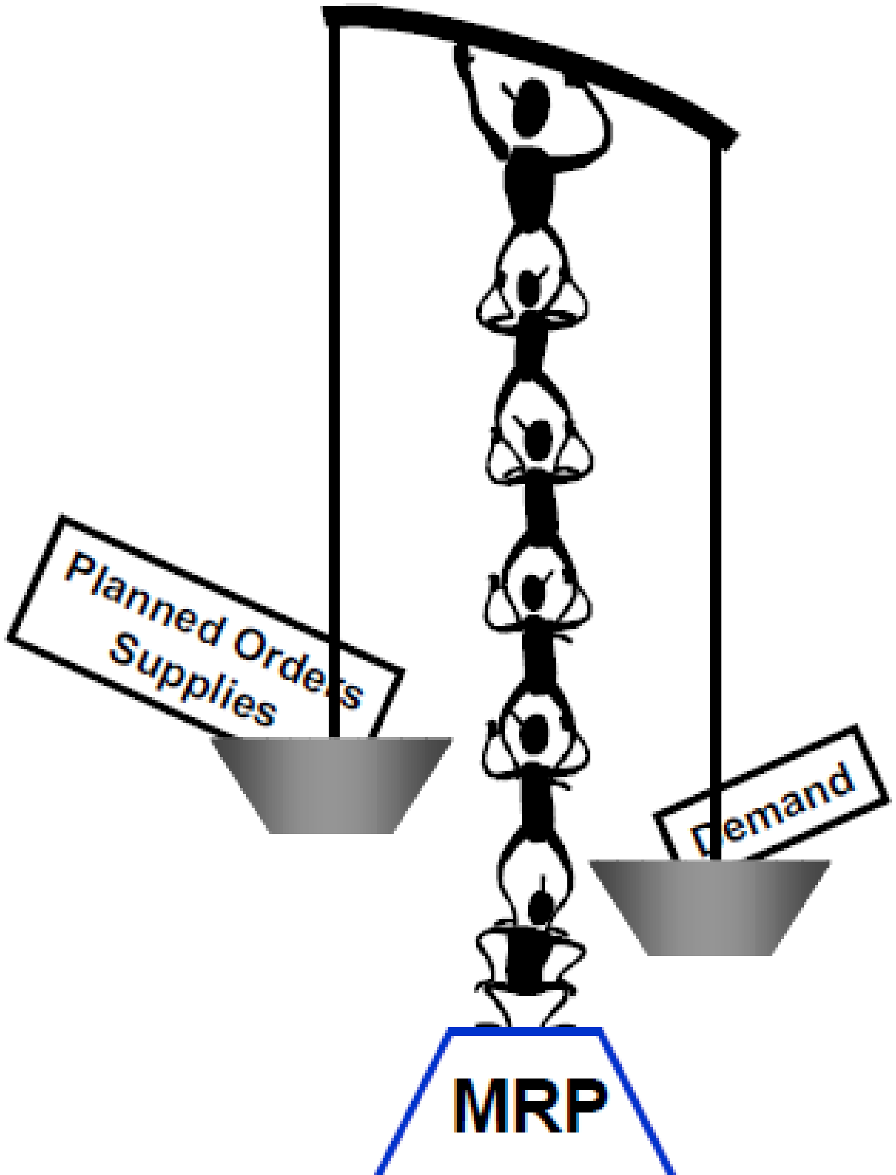
Explanation:
The time needed to assemble 150 chairs is one week.
The assembly department must start assembling chairs in week 1 to have them ready by week 2.

Explanation:
On-hand inventory balance = 17 + 150 – 30 = 137. The MPS quantity is needed to avoid a shortage of 30 – 17 = 13 chairs in week 2.

Material Requirements Planning (MRP)

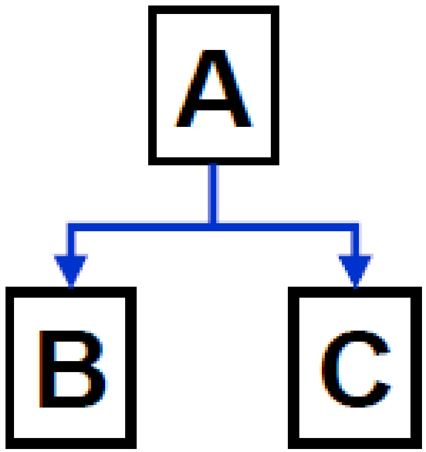
- is software based production planning and inventory control system used to manage manufacturing processes.
- Although it is not common nowadays, it is possible to conduct MRP by hand as well.

Balancing Supply and Demand

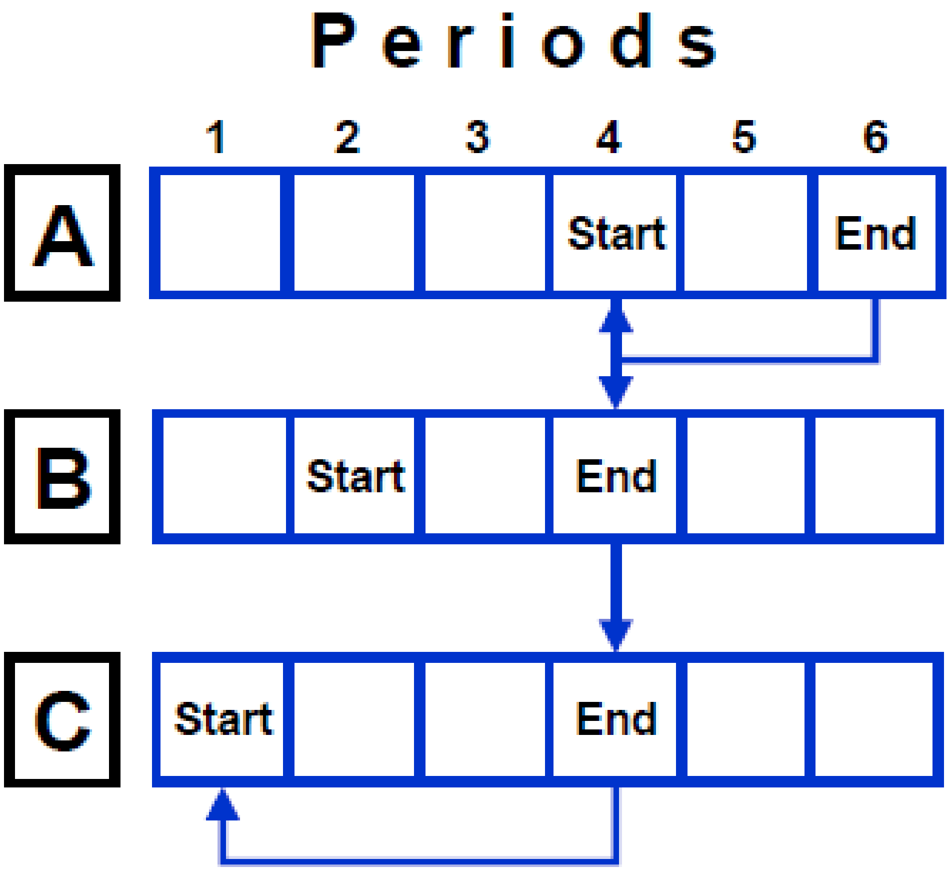


eB-MRP-IN-090

Order Timing



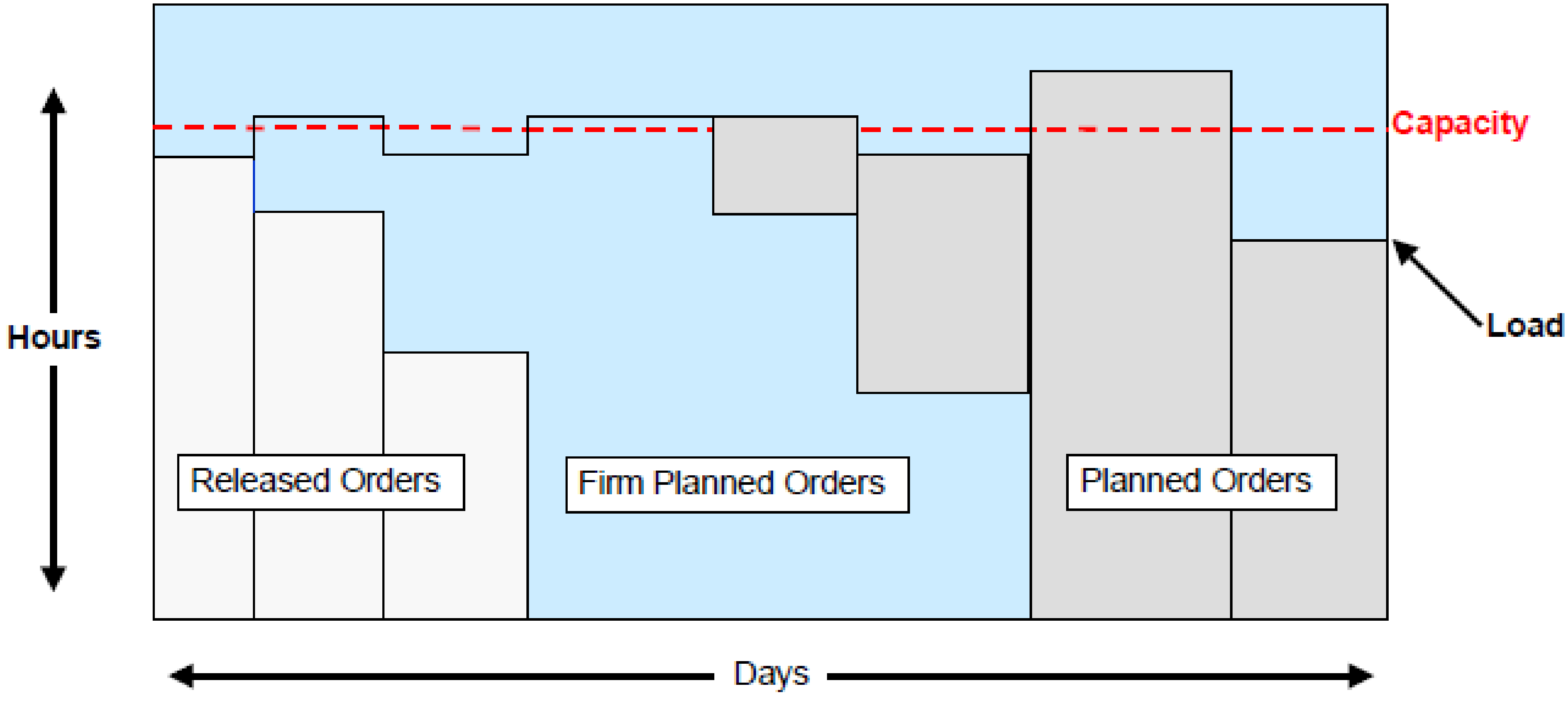
There is demand with
Date Due=Period 6
Lead Times:
A=2
B=2
C=3



Begin work in period 1 to meet the due date

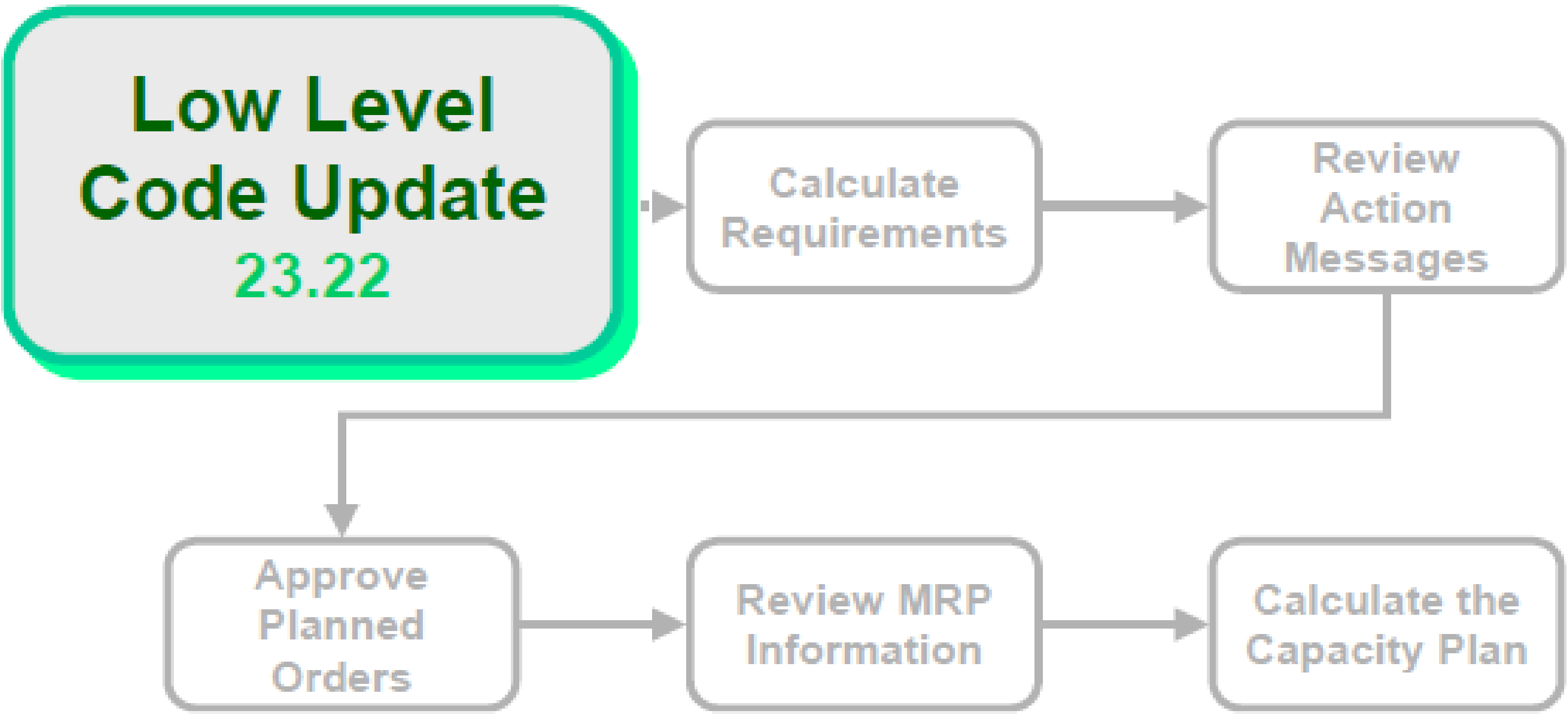
Back Scheduling

Capacity Requirements Planning (CRP)



- Capacity is measured in departmental and work center hours
- Load is measured in hours required by orders in the system

MRP Processing



objectives

- Ensure materials and products are available for production and delivery to customers.
- Maintain the lowest possible level of inventory.
- Plan manufacturing activities, delivery schedules and purchasing activities

HCP

scope of MRP

- *Manufacturing organizations, whatever their products, face the same daily practical problem - that customers want products to be available in a shorter time than it takes to make them. This means that some level of planning is required.*

few examples

- If a company purchases insufficient quantities of an item used in manufacturing, or the wrong item, they may be unable to meet contracts to supply products by the agreed date.
- If a company purchases excessive quantities of an item, money is being wasted - the excess quantity ties up cash while it remains as stock and may never even be used at all.
- Beginning production of an order at the wrong time can cause customer deadlines to be missed.

MRP is a tool to deal with these problems

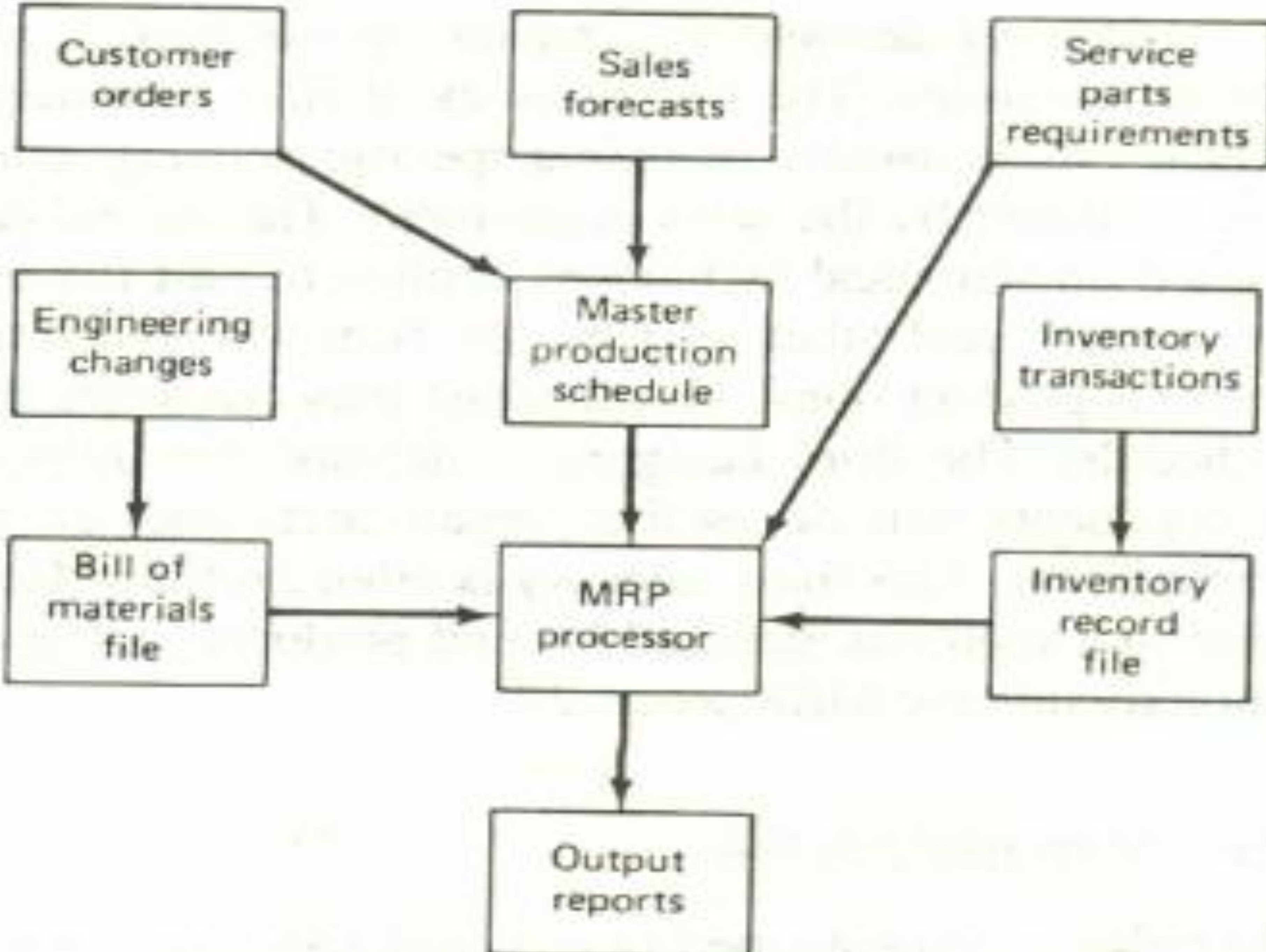
- ***What items are required?***
- ***How many are required?***
- ***When are they required?***

The data that must be considered include

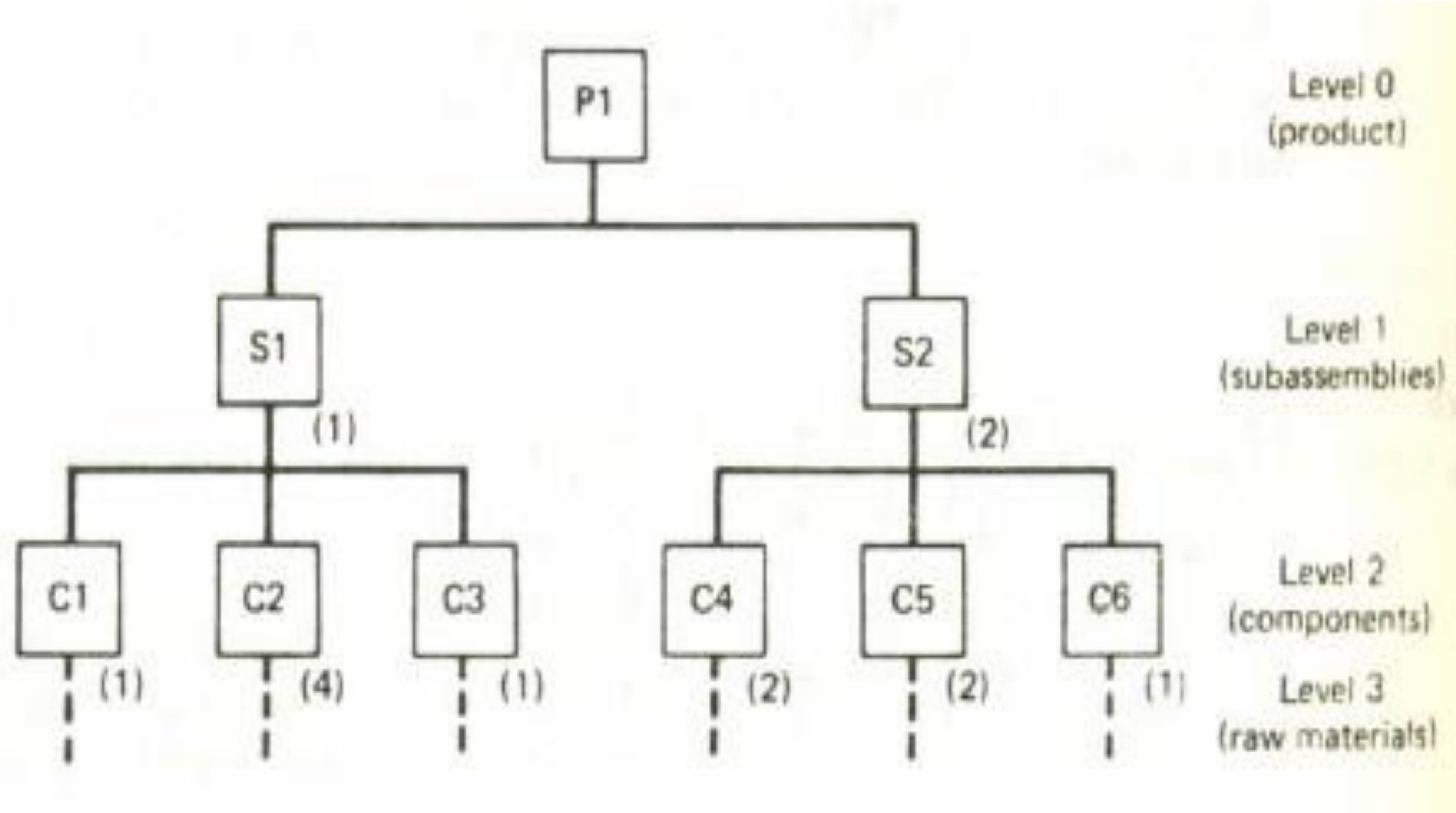
- The *end item (or items) being created. This is sometimes called Independent Demand, or Level "0" on BOM (Bill of materials).*
- How much is required at a time.
- When the quantities are required to meet demand.
- Shelf life of stored materials.
- Inventory status records. Records of *net materials available for use already in stock (on hand) and materials on order from suppliers.*
- Bills of materials. Details of the materials, components and subassemblies required to make each product.
- Planning Data. This includes all the restraints and directions to produce the end items. This includes such items as: Routings, Labor and Machine Standards, Quality and Testing Standards, Pull/Work Cell and Push commands, Lot sizing techniques (i.e. ***Fixed Lot Size, Lot-For-Lot, Economic Order Quantity), Scrap Percentages, and other inputs.***

INPUTS TO MRP

1. The master production schedule and other order data
2. The-bill-of-materials file, which defines the product structure
3. The inventory record file


Customer orders
Sales forecasts
Service parts requirements
Engineering changes
Master production schedule
Inventory transactions
Bill of materials file
MRP processor
Inventory record file
Output reports

Bill of materials file

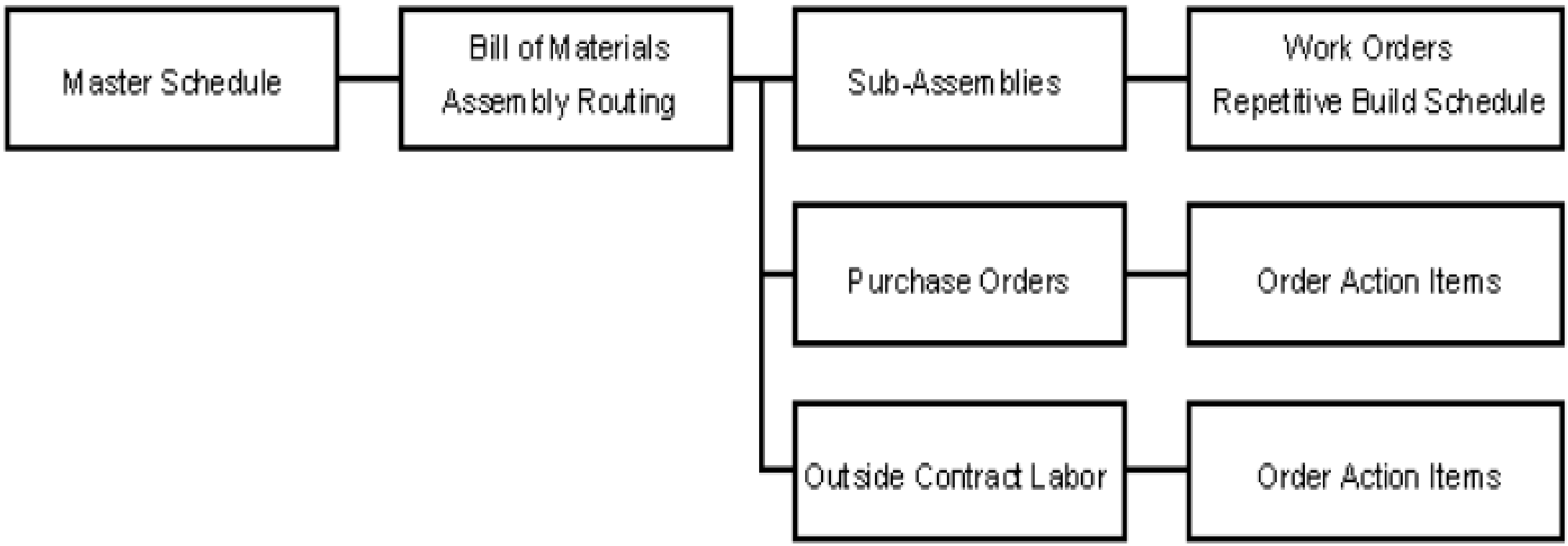


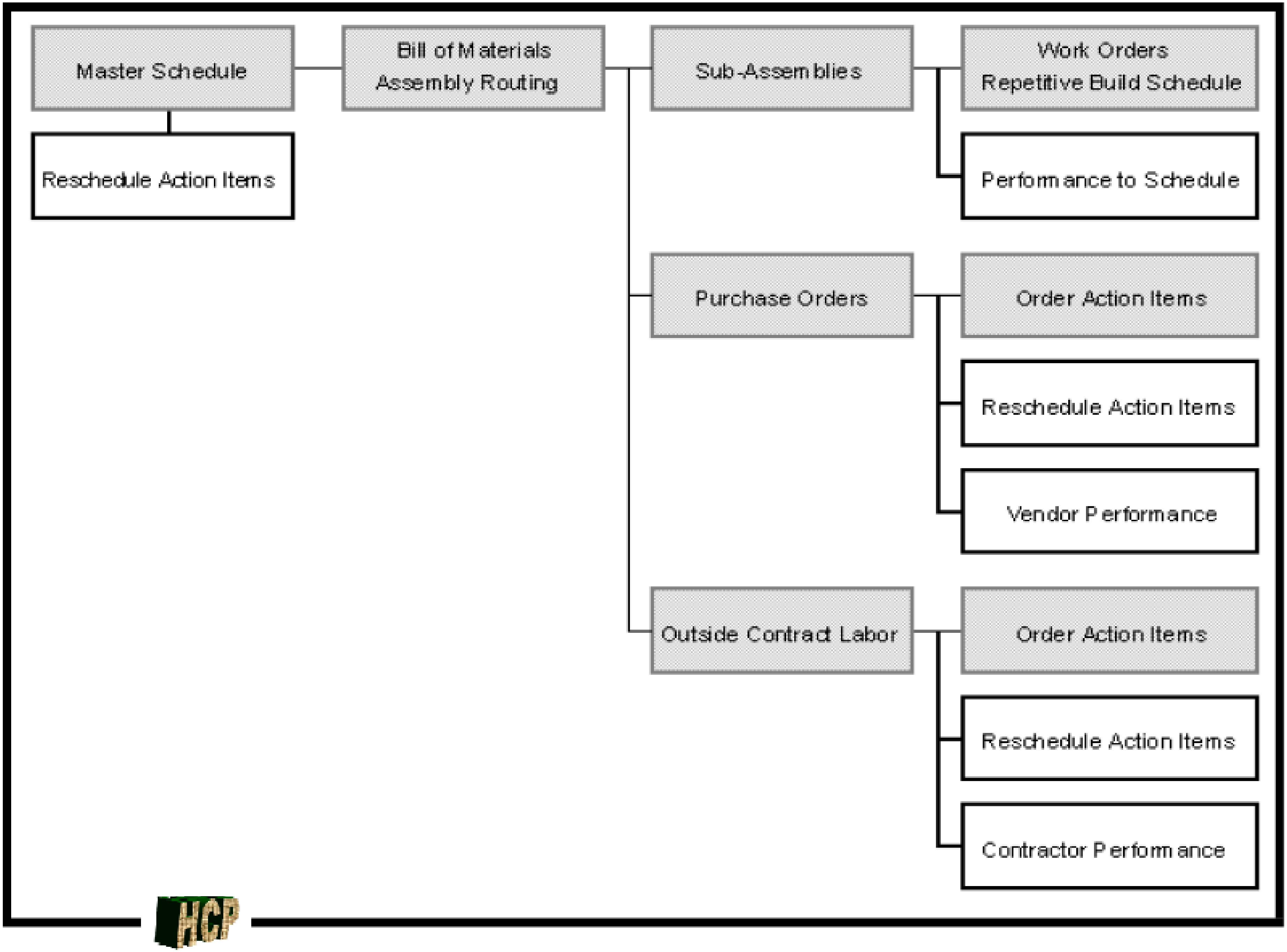
Outputs

- "Recommended Production Schedule" which lays out a detailed schedule of the required minimum start and completion dates, with quantities, for each step of the Routing and Bill Of Material required to satisfy the demand from the MPS.
- "Recommended Purchasing Schedule". This lays out both the dates that the purchased items should be received into the facility AND the dates that the Purchase orders, or Blanket Order Release should occur to match the production schedules.

Messages and Reports

- Purchase orders. An order to a supplier to provide materials.
- Reschedule notices. These *recommend cancelling, increasing, delaying or speeding up existing orders.*


Master Schedule
Bill of Materials
Assembly Routing
Sub-Assemblies
Work Orders
Repetitive Build Schedule
Purchase Orders
Order Action Items
Outside Contract Labor
Order Action Items


Master Schedule
Reschedule Action Items
Bill of Materials
Assembly Routing
Sub-Assemblies
Work Orders
Repetitive Build Schedule
Performance to Schedule
Purchase Orders
Order Action Items
Reschedule Action Items
Vendor Performance
Outside Contract Labor
Order Action Items
Reschedule Action Items
Contractor Performance

MRP II is not

- a computer system
- manufacturing control system
- inventory reduction plan
- Sales & Purchase System
- Material Management

Process Planning

- Analysis of part requirements
- Selection of raw workpiece
- Selection of manufacturing operations and their sequences
- Selection of machine tools
- Selection of tools, tool holding devices, work holding devices and inspection equipments
- Selection of manufacturing conditions i.e. cutting speed, feed and depth of cut.
- Determination of manufacturing times

- Products and their components are designed to perform certain specific functions.
- Every product has some design specifications which ensure its functionality aspects.
- Process planning acts as a bridge between design and manufacturing by translating design specifications into manufacturing process details.
- It refers to a set of instructions that are used to make a component or a part so that the design specifications are met, therefore it is major determinant of manufacturing cost and profitability of products.

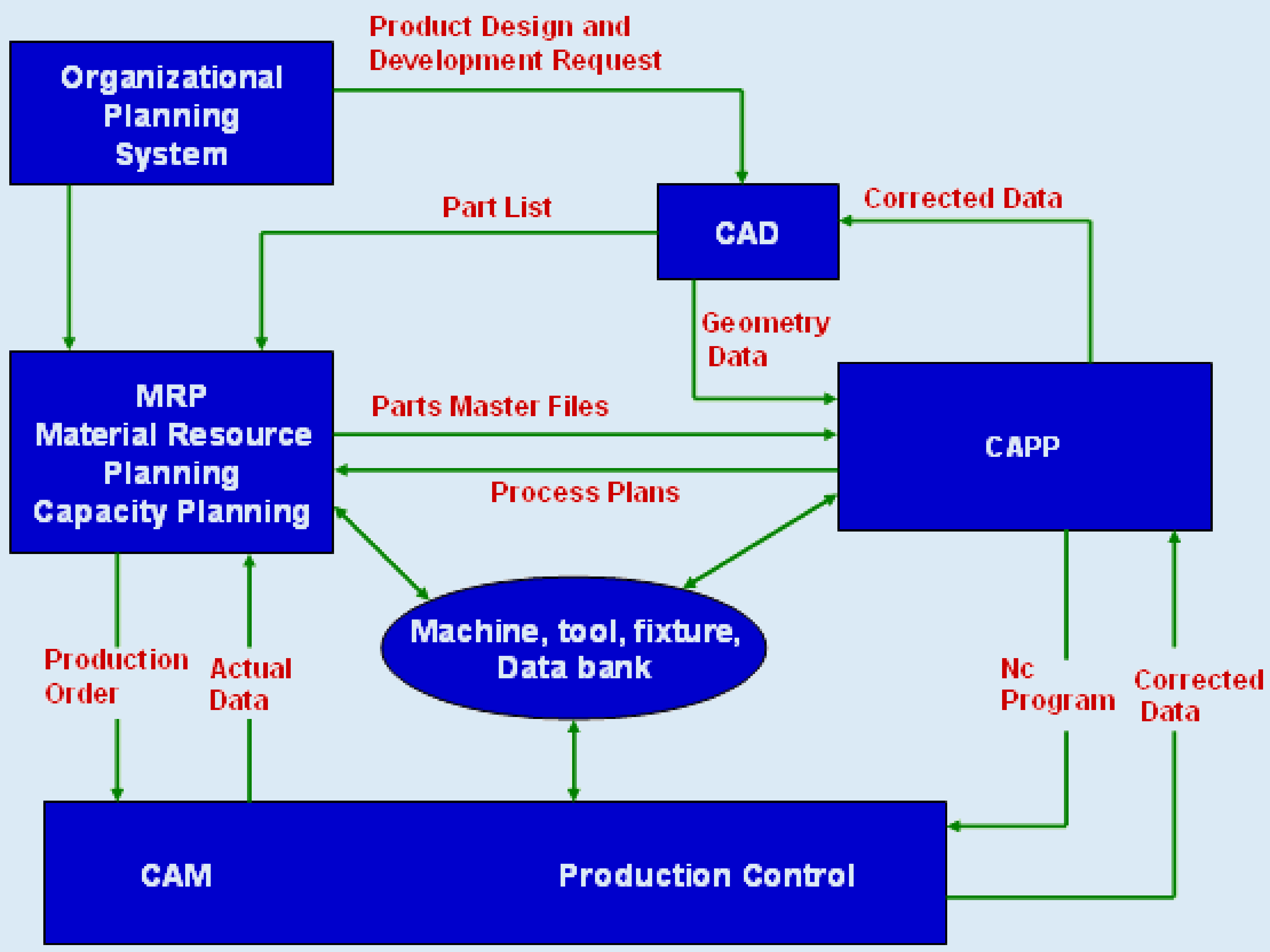
- Process planning answers the questions regarding required information and activities involved in transforming raw materials into a finished product.
- The process starts with the selection of raw material and ends with the completion of part.
- The development of process plans involves mainly a set of following activities

The manual experience-based planning method

- most widely used.
- It is mainly based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes, and tooling.
- The major problem with this approach is that it is time consuming and developed plans may not be consistent and optimum.
- The feasibility of developed process plan is dependant on many factors such as availability of machine tools, scheduling and machine allocation etc.

Computer Aided Process Planning

- CAPP integrates and optimizes system performance into the inter-organizational flow. For example, when one changes the design, it must be able to fall back on CAPP module to generate manufacturing process and cost estimates for these design changes.
- Similarly, in case of machine breakdown on the shop floor, CAPP must generate the alternative actions so that most economical solution can be adopted in the given situation.


Organizational Planning System
Product Design and Development Request
CAD
Part List
Corrected Data
Geometry Data
MRP Material Resource Planning Capacity Planning
Parts Master Files
Process Plans
CAPP
Machine, tool, fixture, Data bank
Production Order
Actual Data
Nc Program
Corrected Data
CAM
Production Control

Advantages

- Systematic development of accurate and consistent process plans
- Reduction of cost and lead time of process planning
- Reduced skill requirements of process planners
- Increased productivity of process planners
- Higher level application programs such as cost and manufacturing lead time estimation and work standards can be interfaced

- Two major methods are used in computer aided process planning; the variant CAPP method and the generative CAPP method
- **(1) The variant CAPP method (**Retrieval-type CAPP systems)
- **(2) The generative CAPP method**

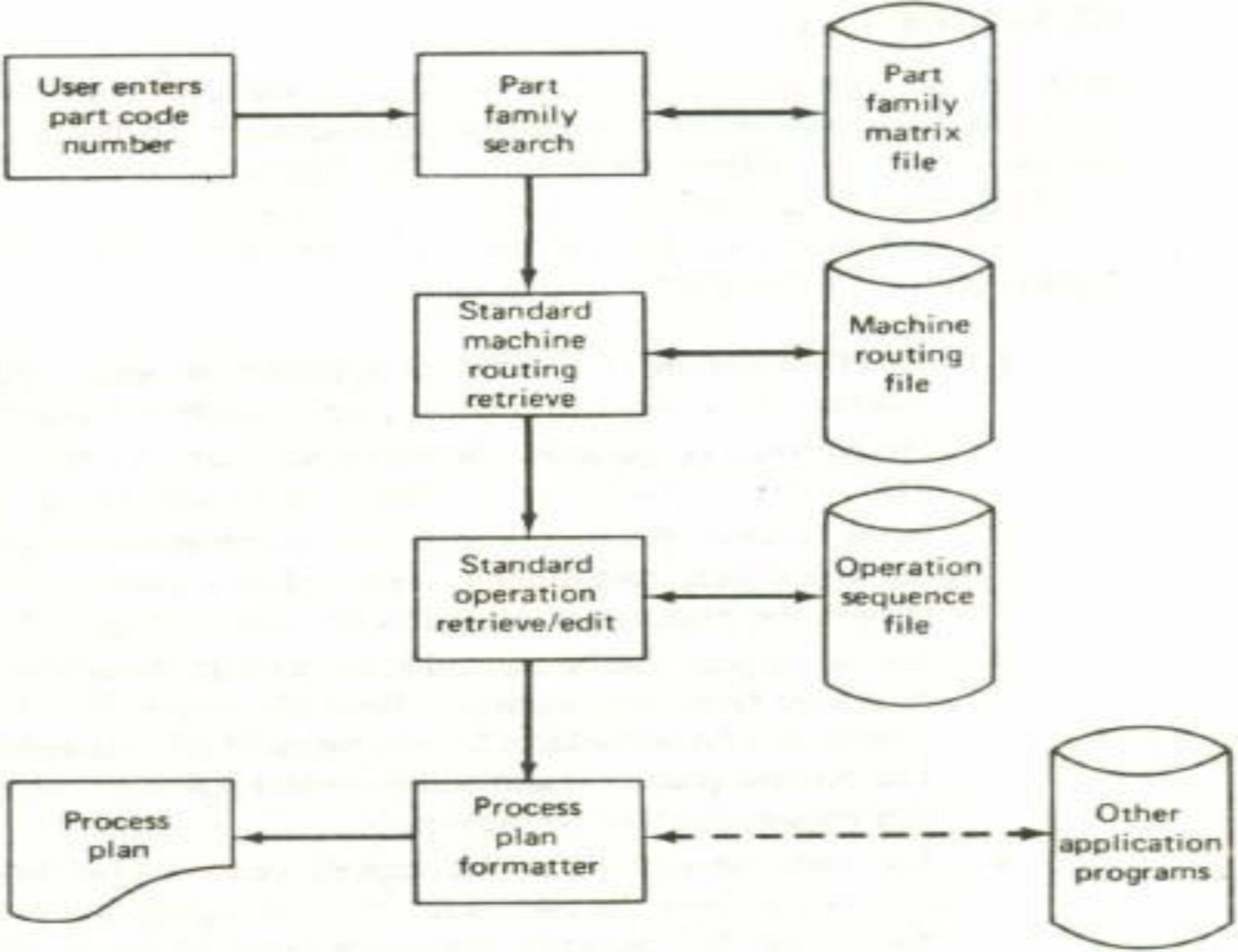
variant CAPP method

- In variant CAPP approach, a process plan for a new part is created by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for the new part.
- Sometimes, the process plans are developed for parts representing a family of parts called 'master parts'.
- The similiarities in design attributes and manufacturing methods are exploited for the purpose of formation of part families.
- A number of methods have been developed for part family formation using coding and classification schemes of group technology (GT), similiarity-coefficient based algorithms and mathematical programming models.

four step process

1. Definition of coding scheme
2. Grouping parts into part families
3. Development of a standard process plan
4. Retrieval and modification of standard process plan

- A number of variant process planning schemes have been developed and are in use.
- One of the most widely used CAPP system is CAM-I developed by McDonnell-Douglas Automation Company.
- This system can be used to generate process plan for rotational, prismatic and sheet-metal parts.



User enters part code number
Part family search
Part family matrix file
Standard machine routing retrieve
Machine routing file
Standard operation retrieve/edit
Operation sequence file
Process plan
Process plan formatter
Other application programs

generative CAPP method

- process plans are generated by means of decision logic, formulas, technology algorithms and geometry based data to perform uniquely many processing decisions for converting part from raw material to finished state.
- There are two major components of generative CAPP; a geometry based coding scheme and process knowledge in form of decision logic data.
- The geometry based coding scheme defines all geometric features for process related surfaces together with feature dimensions, locations, tolerances and the surface finish desired on the features.
- The level of detail is much greater in a generative system than a variant system.

- For example, details such as rough and finished states of the parts and process capability of machine tools to transform these parts to the desired states are provided.
- Process knowledge in form of in the form of decision logic and data matches the part geometry requirements with the manufacturing capabilities using knowledge base.
- It includes selection of processes, machine tools, jigs or fixtures, tools, inspection equipments and sequencing operations. Development of manufacturing knowledge base is backbone of generative CAPP.
- The tools that are widely used in development of this database are flow-charts, decision tables, decision trees, iterative algorithms, concept of unit machined surfaces, pattern recognition techniques and artificial intelligence techniques such as expert system shells.

Advantages of CAPP

- Reduced process planning and production lead-times
- Faster response to engineering changes in the product
- Greater process plan accuracy and consistency
- Inclusion of up-to-date information in a central database
- Improved cost estimating procedures and fewer calculation errors
- More complete and detailed process plans
- Improved production scheduling and capacity utilization
- Improved ability to introduce new manufacturing technology and rapidly update process plans to utilize the improved technology

- There are number of difficulties in achieving the goal of complete integration between various functional areas such as design, manufacturing, process planning and inspection.
- For example, each functional area has its own stand-alone relational database and associated database management system. The software and hardware capabilities among these systems pose difficulties in full integration.
- There is a need to develop single database technology to address these difficulties.

- Other challenges include automated translation of design dimensions and tolerances into manufacturing dimensions and tolerances considering process capabilities and dimensional chains, automatic recognition of features and making CAPP systems affordable to the small and medium scale manufacturing companies.