zPROCESS SCHEDULING ALGORITHMS

Average waiting time: (Avg WT)

- Waiting time = Starting time – Arrival time
- Avg WT = Total WT of all processes / No of processes

Average turn around time: (Avg TAT)

- Turn around time = Finished time – Arrival time
- Avg TAT= Total TAT of all processes / No of processes

Average response time: (Avg RT)

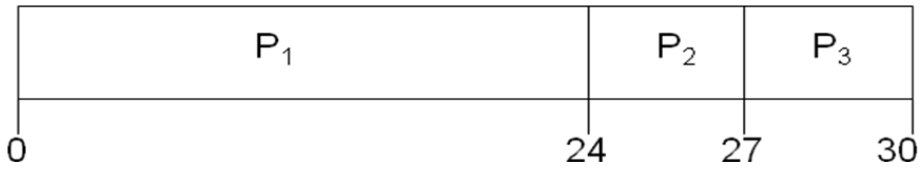
- Response time = First response – Arrival time
- Avg RT= Total RT of all processes / No of processes

QUESTION 1:

Consider a set of three processes P1, P2 and P3 arriving in the order P1, P2, P3 at time instant 0 and having CPU burst times as shown below. Draw the Gantt Chart and calculate the average waiting time, average turn around time and average response time using FCFS algorithm.

Process	Burst time (msecs)
P1	24
P2	3
P3	3

Gantt chart for FCFS:



Average waiting time:

The waiting time for process P1 = 0-0 = 0 msecs

The waiting time for process P2 = 24-0 = 24 msecs

The waiting time for process P3 = 27-0 = 27 msecs

Average waiting time = (0 + 24 + 27) / 3 = 51 / 3 = **17 msecs**

Average turn around time:

The turn around time for process P1 = 24-0 = 24 msecs

The turn around time for process P2 = 27-0 = 27 msecs

The turn around time for process P3 = 30-0 = 30 msecs

Average turn around time = (24 + 27 + 30) / 3 = 81 / 3 = **27 msecs**

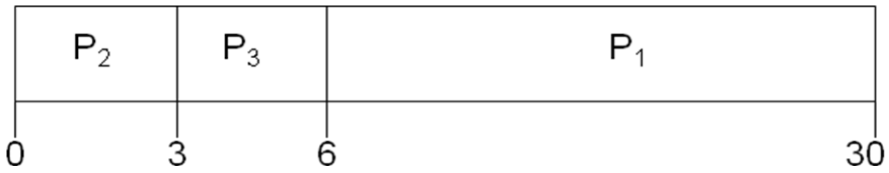
Average response time:

The response time for process P1 = 0-0 = 0 msecs
The response time for process P2 = 24-0 = 24 msecs
The response time for process P3 = 27-0 = 27 msecs
Average response time = (0 + 24 + 27) / 3 = 51 / 3 = **17 msecs**

QUESTION 2:

Find the results for the above data if the processes arrive in the order P2, P3 and P3.

Gantt Chart for FCFS:



Waiting time for P1 = 6-0 = 6; P2 = 0-0 = 0; P3 = 3-0 = 3
Average waiting time = (0 + 3 + 6) / 3 = 9 / 3 = **3 msecs**

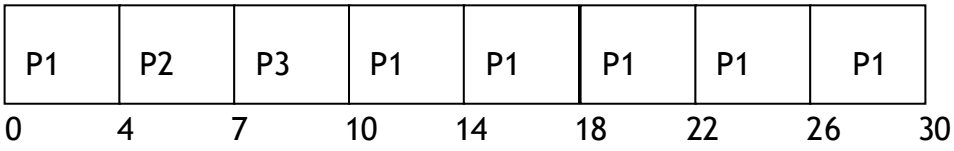
Turn around time for P1 = 3-0 = 3; P2 = 6-0 = 6; P3 = 30-0 =30
Average turnaround time = (3 + 6 + 30) / 3 = 39 / 3 = **13 msecs**

Response time for P1 = 0; P2 = 3-0 = 3; P3 = 6-0 = 6
Average response time = (0 + 3 + 6) / 3 = 9 / 3 = **3 msecs**

QUESTION 3:

Draw the Gantt Chat and find the average waiting time for the above data using RR algorithm with quantum = 4 ms.

Gantt Chart using RR:



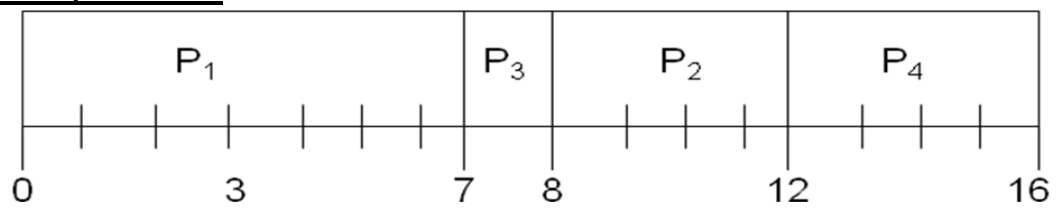
Average waiting time = ((0+(10-4)) + (4) + (7)
= (6 + 4 + 7) / 3 = 17 / 3 = **5.67 msecs**

QUESTION 4:

Given below are the arrival and burst times of four processes P1, P2, P3 and P4. Draw the Gantt Chart using SJF preemptive and non-preemptive scheduling and calculate the average waiting time.

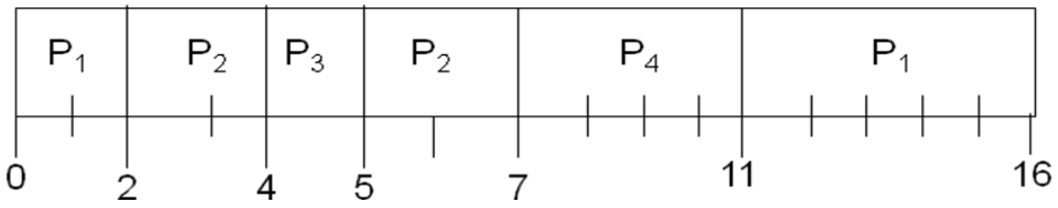
Process	Arrival Time	Burst Time
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4

Non preemptive SJF:



Average waiting time = (0 + (8-2) + (7-4) + (12-5))/4
= (0 + 6 + 3 + 7)/4 = 16/4 = **4 ms**

Preemptive SJF:



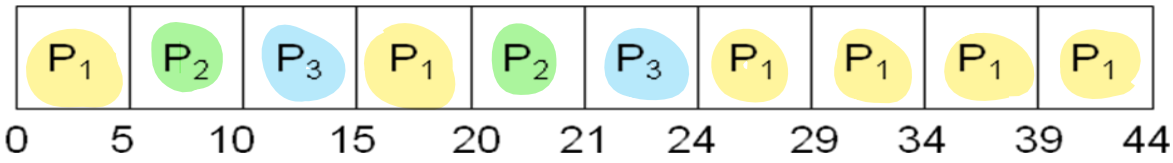
Average waiting time = ((11-2) + (5-4) + 0 + (7-2))/4
= (9 + 1 + 0 +2)/4 = 12/4 = **3 ms**

QUESTION 5:

Given below are the burst times of three processes P1, P2 and P3. Draw the Gantt Chart using RR scheduling and calculate the average waiting time, average turn around time and average response time.
Quantum = 5 ms.

Process	Burst Time
P1	30
P2	6
P3	8

The Gantt chart using RR:



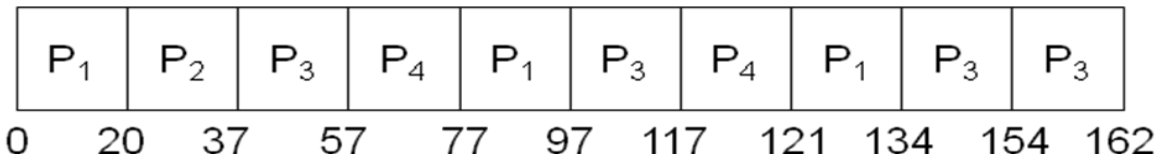
Average waiting time = ((0 + (15-5) + (24-20)) + ((5-0) + (20-10)) + ((10-0) + (21-15))/3
= (14 + 15 + 16)/3 = 45/3 = **15 ms**
Average TAT = (44 + 21 + 24)/3 =89/3 = **29.66 ms**
Average RT = (0 + 5 + 10)/3 = 15/3 = **5 ms**

QUESTION 6:

Given below are the burst times of four processes P1, P2, P3 and P4. Draw the Gantt Chart using RR scheduling and calculate the average waiting time. Quantum = 20 ms.

Proces	Burst Time
P1	53
P2	17
P3	68
P4	24

The Gantt chart is:



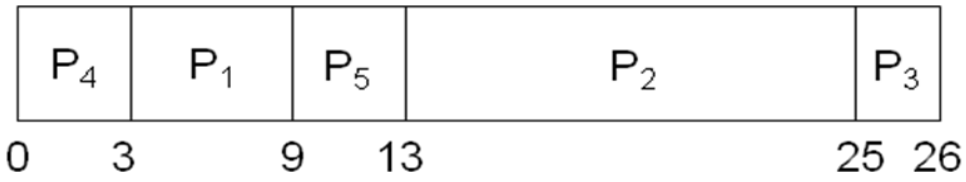
Average WT = (81 + 20 + 94 + 97) / 4 = 292 / 4 = **73 ms**

QUESTION 7:

Given below are the burst times and priorities of five processes P1, P2, P3, P4 and P5. Draw the Gantt Chart using priority scheduling and calculate the average waiting time, turn around time and response time. (a smaller priority number implies a higher priority)

Proces	Burst Time	Priority
P1	6	2
P2	12	4
P3	1	5
P4	3	1
P5	4	3

The Gantt chart is:



Average WT = (3 + 13+ 25 + 0 + 9)/5 = 50/5 = **10 ms**
Average TAT = (9 + 25 + 26 + 3 + 13)/5 =76/5 = **15.2 ms**
Average RT = (3 + 13 + 25 + 0 + 9)/5 =50/5 = **10 ms**

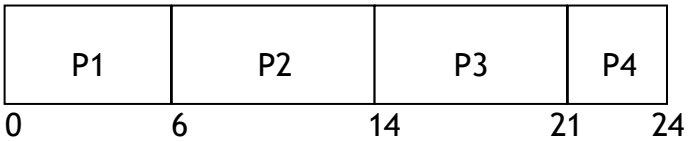
QUESTION 8:

Consider the following set of processes P1, P2, P3, P4 (arriving in the order P1, P2, P3, P4) and their CPU burst times. Use FCFS and SJF algorithm to draw the Gantt Chart and to calculate the average waiting time, average turn around time and average response time. Analyze the results.

Process	Burst time (msecs)
P1	6
P2	8
P3	7
P4	3

FCFS Algorithm:

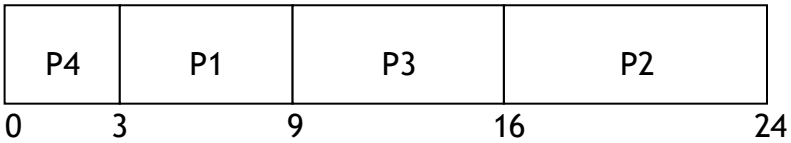
Gantt Chart for FCFS:



Average waiting time = (0 + 6 + 14 + 21) / 4 = 41 / 4 = **10.25 msecs**
Average turn around time = (6 + 14 + 21 + 24) / 4 = 65 / 4 = **16.25 msecs**
Average response time = (0 + 6 + 14 + 21) / 4 = 41 / 4 = **10.25 msecs**

SJF Algorithm:

Gantt Chart for SJF:



Average waiting time = (0 + 3 + 9 + 16) / 4 = 28 / 4 = **7 msecs**

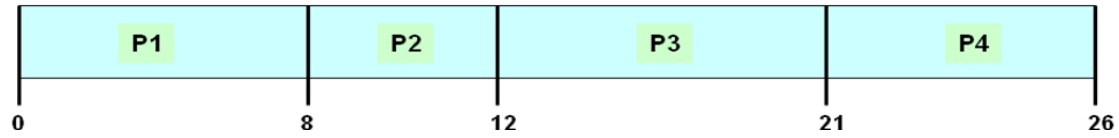
Average turn around time = (3 + 9 + 16 + 24) / 4 = 52 / 4 = **13 msecs**
Average response time = (0 + 3 + 9 + 16) / 4 = 28 / 4 = **7 msecs**

Analysis:
Average waiting time using SJF is less than that sing FCFS. So SJF gives better CPU utilization.

QUESTION 9:
Given below are the arrival and burst times of four processes P1, P2, P3 and P4. Draw the Gantt Chart using FCFS, SJF preemptive, SJF non-preemptive and RR scheduling (Quantum = 4ms, no priority based preemption). Calculate the average waiting time, average turn around time and average response time.

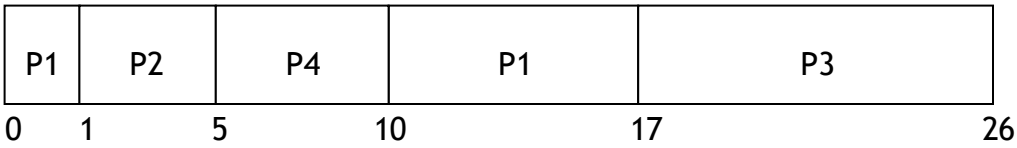
Process	Arrival time (msecs)	Burst time (msecs)
P1	0	8
P2	1	4
P3	2	9
P4	3	5

FCFS:



Average waiting time = ((0-0) + (8-1) + (12-2) + (21-3))/4
= (0 + 7 + 10 + 18)/4 = 35/4 = **8.75 msecs**
Average turn around time = ((8-0) + (12-1) + (21-2) + (26-3))/4
= (8 + 11 + 19 + 23)/4 = 61/4 = **15.25 msecs**
Average response time = ((0-0) + (8-1) + (12-2) + (21-3))/4
= (0 + 7 + 10 + 18)/4 = 35/4 = **8.75 msecs**

Preemptive SJF:



Average waiting time:
The waiting time for process P1 = (0-0) + (10–1) = 9 msecs
The waiting time for process P2 = 1-1 = 0 msecs
The waiting time for process P3 = 17-2 = 15 msecs
The waiting time for process P4 = 5-3 = 2 msecs
Average waiting time = (9 + 0 + 15 + 2) / 4 = 26 / 4 = **6.5 msecs**

Average turn around time:

The turn around time for process P1 = 17-0 = 17 msecs

The turn around time for process P2 = 5-1 = 4 msecs

The turn around time for process P3 = 26-2 = 24 msecs

The turn around time for process P4 = 10-3 = 7 msecs

Average turn around time = (24 + 27 + 30) / 4 = 52 / 4 = **13 msecs**

Average response time:

The response time for process P1 = 0-0 = 0 msecs

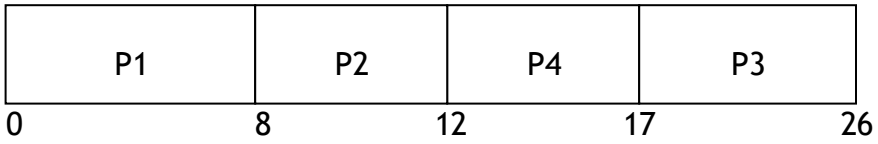
The response time for process P2 = 1-1 = 0 msecs

The response time for process P3 = 17-2 = 15 msecs

The response time for process P4 = 5-3 = 2 msecs

Average response time = (0 + 0 + 15 + 2) / 4 = 17 / 4 = **4.25 msecs**

Non-preemptive SJF:



Average waiting time = ((0 – 0) + (8 – 1) + (17 – 2) + (12 – 3)) / 4

= (0 + 7 + 15 + 9) / 4 = 31 / 4 = **7.75 msecs**

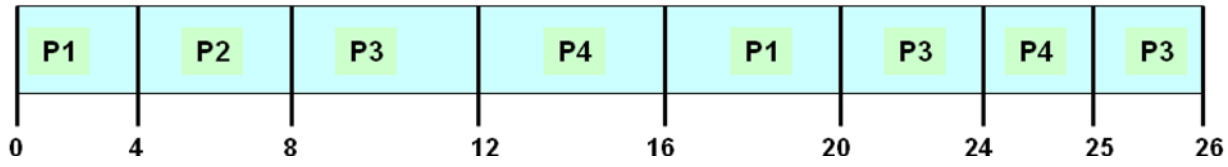
Average turn around time = ((8 – 0) + (12 – 1) + (26 – 2) + (17 – 3)) / 4

= (8 + 11 + 24 + 14) / 4 = 57 / 4 = **14.25 msecs**

Average response time = ((0 – 0) + (8 – 1) + (17 – 2) + (12 – 3)) / 4

= (0 + 7 + 15 + 9) / 4 = 31 / 4 = **7.75 msecs**

RR Scheduling:



Average waiting time:

WT of P1 = ((0–0) + (16–4)) = 0 + 12 = 12

WT of P2 = (4–1) = 3

WT of P3 = ((8-2) + (20-12) + (25-24)) = 6 + 8 + 1 = 15

WT of P4 = ((12-3) + (24-16)) = 9 + 8 = 17

Average waiting time = (12 + 3 + 15 + 17)/4 = 47 / 4 = **11.75 msecs**

Average turn around time = ((20 – 0) + (8 – 1) + (26 – 2) + (25 – 3)) / 4
= (20 + 7 + 24 + 22) / 4 = 73 / 4 = **18.25 msecs**

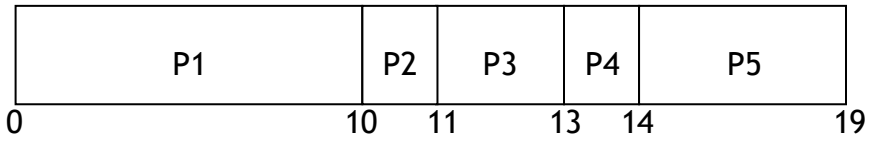
Average response time = ((0 – 0) + (4 – 1) + (8 – 2) + (12 – 3)) / 4
= (0 + 3 + 6 + 9) / 4 = 18 / 4 = **4.5 msecs**

QUESTION 10: (University Question)
Given below are the burst times ad priorities of four five processes P1, P2, P3, P4 and P5. The processes are assumed to have arrived in the order P1, P2, P3, P4, P5, all at time 0.

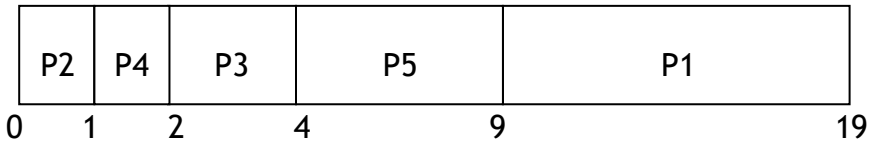
Process	Priority	Burst time (msecs)
P1	3	10
P2	1	1
P3	3	2
P4	4	1
P5	2	5

a. Draw four Gantt charts illustrating the execution of these processes using FCFS, SJF, non preemptive priority (a smaller priority number implies a higher priority), and RR (quantum = 1) scheduling.
b. What is the turnaround time of each process for each of the scheduling algorithms?
c. What is the waiting time of each process for each of the scheduling algorithms?
d. Which of the schedules in part results in the minimal average waiting time?

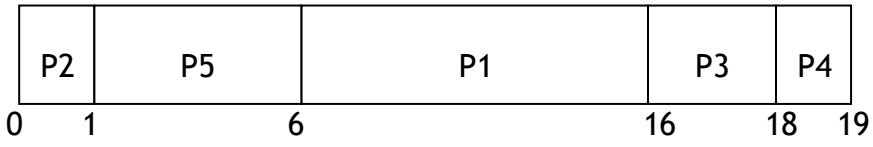
a. Gantt Charts:
For FCFS:



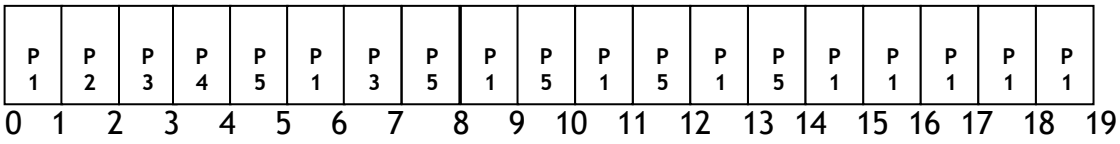
For SJF:



For Non Preemptive Priority Scheduling:



For RR Scheduling:



b. Turn Around Time:

For FCFS:

TAT for P1 = 10 ms TAT for P2 = 11 ms TAT for P3 = 13 ms
TAT for P4 = 14 ms TAT for P5 = 19 ms
Average TAT = (10 + 11 + 13 + 14 + 19)/5 = 67 / 5 = **13.4 ms**

For SJF:

TAT for P1 = 19 ms TAT for P2 = 1 ms TAT for P3 = 4 ms
TAT for P4 = 2 ms TAT for P5 = 9 ms
Average TAT = (19 + 1 + 4 + 2 + 9)/5 = 35 / 5 = **7 ms**

For non preemptive priority:

TAT for P1 = 16 ms TAT for P2 = 1 ms TAT for P3 = 18 ms
TAT for P4 = 19 ms TAT for P5 = 6 ms
Average TAT = (16 + 1 + 18 + 19 + 6)/5 = 60 / 5 = **12 ms**

For RR:

TAT for P1 = 19 ms TAT for P2 = 2 ms TAT for P3 = 7 ms
TAT for P4 = 4 ms TAT for P5 = 14 ms
Average TAT = (19 + 2 + 7 + 4 + 14)/5 = 46 / 5 = **9.2 ms**

c. Waiting Time:

For FCFS:

WT for P1 = 0 ms WT for P2 = 10 ms WT for P3 = 11 ms
WT for P4 = 13 ms WT for P5 = 14 ms
Average WT = (0 + 10 + 11 + 13 + 14)/5 = 48 / 5 = **9.6 ms**

For SJF:

WT for P1 = 9 ms WT for P2 = 0 ms WT for P3 = 2 ms
WT for P4 = 1 ms WT for P5 = 4 ms
Average WT = (9 + 0 + 2 + 1 + 4)/5 = 16 / 5 = **3.2 ms**

For non preemptive priority:

WT for P1 = 6 ms WT for P2 = 0 ms WT for P3 = 16 ms
WT for P4 = 18 ms WT for P5 = 1 ms
Average WT = (6 + 0 + 16 + 18 + 1)/5 = 41 / 5 = **8.2 ms**

For RR:

WT for P1 = 0+(5-1)+(8-6)+(10-9)+(12-11)+(14-13) = 0+4+2+1+1+1 = 9 ms
WT for P2 = (1-0) = 1 ms
WT for P3 = (2-0)+(6-3) – 2+3 = 5 ms

WT for P4 = (3-0) = 3 ms
WT for P5 = (4-0)+(7-5)+(9-8)+(11-10)+(13-12) = 4+2+1+1+1 = 9 ms
Average WT = (9 + 1 + 5 + 3 + 9)/5 = 27 / 5 = **5.4 ms**

d. Minimum Average Waiting Time:

SJF Scheduling provides the minimum average waiting time of **3.2 ms.**

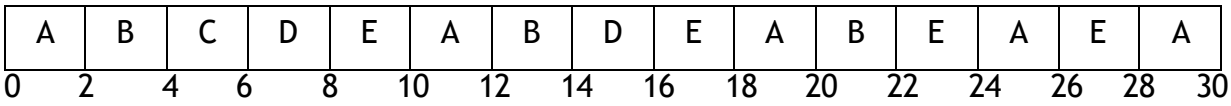
QUESTION 11:

Find the mean turn around time for the following data for each of the following algorithms.

a. Round Robin (Quantum = 2 minutes)
b. Priority Scheduling
c. First Come First Serve (In the order 10, 6, 2, 4 and 8)
d. Shortest Job First

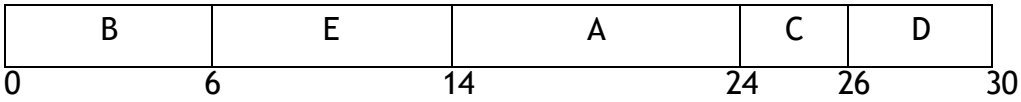
Estimated runtimes for five batch jobs A through E: 10, 6, 2, 4 and 8 minutes. Assume that they all have arrival time as 0. Their determined priorities are 3, 5, 2,1 and 4 respectively with 5 being the highest priority.

a. Gantt Chart for RR:



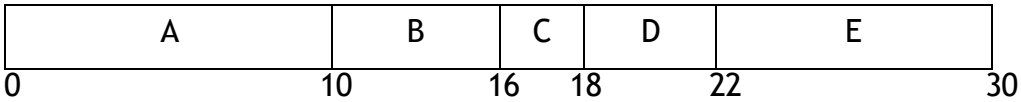
Mean TAT = (30+22+6+16+28)/5 = 102/5 = **20.4 ms**

b. Gantt Chart for Priority Scheduling:



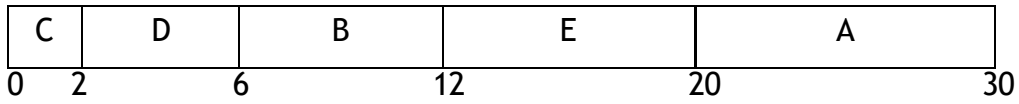
Mean TAT = (24+6+26+30+14)/5 = 100/5 = **20 ms**

c. Gantt Chart for FCFS:



Mean TAT = (10+16+18+22+30)/5 = 96/5 = **19.2 ms**

d. Gantt Chart for SJF:



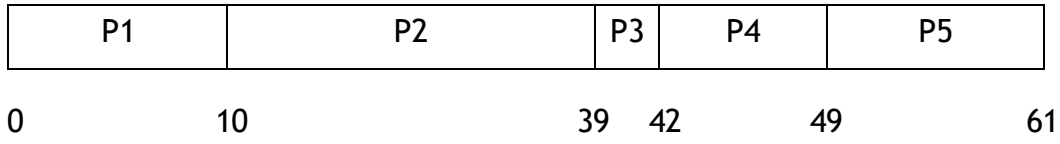
Mean TAT = (30+12+2+6+20)/5= 70/5 = **14 ms**

QUESTION 12: (University Question)

All 5 processes arrive at time 0, in the order given, with the length of the CPU-burst time given in milliseconds. Consider FCFS, SJF and RR scheduling (quantum = 10 ms) scheduling algorithms for this set of processes. Calculate the waiting time and find out which algorithm would give the minimum average waiting time.

Process	Burst Time
P1	10
P2	29
P3	3
P4	7
P5	12

Gantt Chart for FCFS:



Waiting time = Starting time-Arrival time

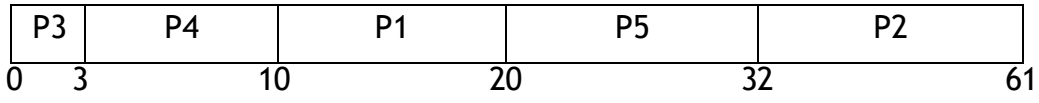
P1, waiting time=0-0=0 P2, waiting time=10-0=10

P3, waiting time=39-0=39 P4, waiting time=42-0=42

P5, waiting time=49-0=49

Average waiting time=0+10+39+42+49/5 = 140/5 = **28 ms**

Gantt Chart for SJF:



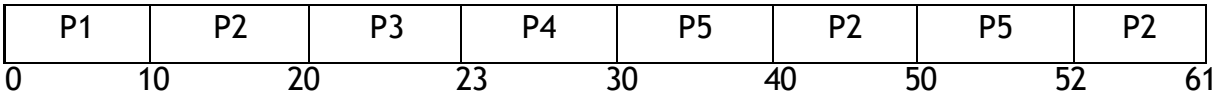
P1, waiting time=10-0=10 P2, waiting time=32-0=32

P3, waiting time=0-0=0 P4, waiting time=3-0=3

P5, waiting time=20-0=20

Average waiting time=10+32+0+3+20/5 = 65/5 = **13 ms**

Gantt Chart for RR:



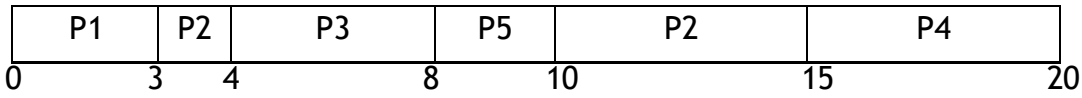
P1, waiting time=0-0=0
P2, waiting time=(10-0)+(40-20)+(52-50)=10+20+2=32
P3, waiting time=20-0=20 P4, waiting time=23-0=23
P5, waiting time=(30-0)+(50-40)=30+10=40
Average waiting time=0+32+20+23+40/5 = 115/5 = **23ms**

Therefore **SJF algorithm** is having the shortest average waiting time.

QUESTION 13:
Consider the following processes. Draw Gantt chart illustrating the execution of the given processes using Shortest Remaining Time Next scheduling algorithm. Calculate the Average waiting Time and Average Turn around Time.

Process	Burst Time	Arrival Time
P1	3	0
P2	6	2
P3	4	4
P4	5	6
P5	2	8

Gantt Chart for SRTN:



Average WT = ((0) + ((3-2)+(10-4)) + (4-4) + (8-8)) / 5 = (0 + 7 + 0 + 0)/5
= 7/5 = **1.4 ms**

Average TAT = ((3-0) + (15-2) + (8-4) + (20-6) + (10-8))/5 = (3+13+4+14+2)/5
= 36/5 = **7.2 ms**

QUESTION 14:
Consider the following set of processes P1, P2, P3, P4 and their CPU burst times. Using SJF algorithm, calculate average waiting time and average turn around time.

Process	Burst time (msecs)
P1	6

P2	8
P3	7
P4	3

QUESTION 15:

Calculate the average waiting time with respective to preemptive Shortest Job First (SRT) Scheduling algorithm.

Process	Burst Time
P1	3
P2	10
P3	4

QUESTION 16:

Assume you have the following jobs to execute with one processor, with the jobs arriving in the order listed here:

Process	Processing Time	Priority
1	80	3
2	20	1
3	10	4
4	20	5
5	50	2

Suppose a system uses FCFS scheduling

a. Draw a timing chart illustrating the execution of these processes.
b. What is the turnaround time for process p4?
c. What is the average wait time for the processes?

Now assume the system uses priority scheduling where a small integer means a high priority

d. Draw a timing chart illustrating the execution of these processes.
e. What is the turnaround time for process p2?
f. What is the average wait time for the processes?

QUESTION 17:

Consider the following set of processes, with the length of the CPU-burst time and the arrival time given in milliseconds. Draw a Gantt chart illustrating the execution of these processes using preemptive SJF scheduling algorithm.

Process Arrival Time Burst Time

P1	0	75
P2	10	40
P3	10	25
P4	80	20
P5	85	45

QUESTION 18:

Draw the Gantt chart for the Shortest Remaining Time Next SRTN scheduling policy and calculate the average turn around time, average waiting time, throughput and processor utilization for the following set of processes that arrive at a given arrival time shown in the following table.

Process	Arrival time	Processing time
P1	0	2
P2	1	1
P3	3	2
P4	4	3
P5	6	5

QUESTION 19: (University Question)

For the processes listed below, find the average turn around time and waiting time (rounding to the nearest hundredth) for round robin scheduling for a time interval 2.

Process	Arrival Time	Processing time
A	0.000	3
B	1.001	6
C	4.001	4
D	6.001	2

QUESTION 20 (University Question)

The following series of processes with the given run-times arrives in the ready queue in the order shown. For FCFS and SJF scheduling policies, calculate the waiting time and the wait-time/run-time ratio of each process. Comment on results.

Job	Estimate run-time
1	10
2	50
3	2
4	100
5	5

Briefly explain any two non-preemptive scheduling algorithms.

(Balarishna Prasad Text Book Problems)

QUESTION 21:

Draw the Gantt chart for FCFS scheduling policy and calculate the average turn around time, average waiting time and average response time for the following set of processes that arrive at a time 0.

Process	Processing time
P1	5
P2	24
P3	16
P4	10
P5	3

Avg TAT = 37.4 ms (38.4)
Avg WT = 25 ms (26.8)
Avg RT = 25 ms

QUESTION 22:

Draw the Gantt chart for FCFS scheduling policy and calculate the average turn around time, average relative delay and average response time for the following set of processes that arrive at a time given below.

Process	Arrival Time	Processing time
P1	0	3
P2	2	6
P3	4	4
P4	6	5
P5	8	2

Average Relative Delay (Normalized Turn Around Time= Turn Around Time / Burst Time or Service Time

Avg TAT = 8.60 ms
Avg relative delay = 2.56 ms
Avg RT = 4.6 ms

QUESTION 23:

Draw the Gantt chart for SJF scheduling policy and calculate the average turn around time, average waiting time and average response time for the following set of processes that arrive at a time 0.

Process	Processing time
P1	5

P2	24
P3	16
P4	10
P5	3

Avg TAT = 24.2 ms
Avg WT = 12.6 ms
Avg RT = 12.6 ms

QUESTION 24:

Draw the Gantt chart for RR scheduling policy with quantum = 5ms and calculate the average turn around time, average waiting time and average response time for the following set of processes that arrive at a time 0.

Process	Processing time
P1	30
P2	6
P3	8

Avg TAT = 29.66 ms
Avg WT = 15 ms
Avg RT = 3 ms

QUESTION 25:

Consider the following set of processes and CPU burst times. Calculate the average WT, avg RT and avg TAT for the algorithms FCFS, SJF, RR (quantum = 3 ms) and priority scheduling. Which one is the best algorithm?

Process	Burst time	Priority
P1	5	4
P2	12	1
P3	16	3
P4	18	5
P5	2	2

QUESTION 26:

Consider the following set of processes, calculate the normalized turn around time with the help of SJF algorithm.

Process	Arrival time	Process Time
P1	0	6
P2	5	10

P3	7	13
P4	11	2
P5	13	6

QUESTION 27:

Suppose a system uses priority scheduling, where a small integer means a high priority. Calculate the average waiting time.

Process	Burst time	Priority
P1	8	3
P2	2	1
P3	5	4
P4	3	2
P5	6	5

QUESTION 28:

Consider the following set of processes. Calculate the average waiting time for all scheduling algorithms and identify which is the best algorithm. Quantum = 2 ms.

Process	Burst Time	Arrival Time
P1	3	0
P2	5	1
P3	2	3
P4	5	9
P5	5	12

QUESTION 29:

Consider the following set of processes. Calculate the average waiting time for all scheduling algorithms and identify which is the best algorithm. Quantum = 1 ms.

Process	Burst Time	Arrival Time
P1	1	0
P2	100	1
P3	1	2
P4	100	3

QUESTION 30 (University Question)

Consider five processes with the length of CPU burst time, Arrival time and Priority (small value means high priority)

Process	Burst Time	Arrival Time	Priority
P1	40	0	3
P2	55	15	2

P3	35	15	1
P4	10	35	5
P5	30	40	4

(i) Create Gantt charts illustrating the execution of these processes using FCFS, non preemptive SJF, priority scheduling and Round Robin scheduling (quantum = 5 ms) algorithms for this set of processes.

(ii) Calculate the turn around time for process P3 under each of the above algorithms.

(iii) Calculate average waiting time for each algorithm and find out which algorithm would give the minimum average waiting time.