Chapter 5

Network Analysis and Queuing Theory

CHAPTER HIGHLIGHTS

- *Project and Network*
- *Activity and Event*
- *Dummy Activity*
- *Network Diagrams*
- *Slack and Float*
- *Critical Path and Critical Path Method (CPM)*
- *Program Evaluation and Review Technique (PERT)*
- *Queuing Theory*
- *Expected Number in the Queue*
- *Expected Time in the Queue*
- *Expected Time in the System*
- *Important Formulae in Queuing Theory*

PROJECT AND NETWORK

A project is an one time job. It is composed of activities, functions, tasks etc. which are inter-related. They are to be completed systematically for the project to be completed. In a large project, a number of jobs are done simultaneously. Also, these are activities whose starting and ending dates are critical with regard to other jobs and tasks in the project. Network is the combination of activities and events of a project arranged in a logical sequence and then represented graphically.

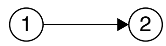
Network problems are solved by network analysis. Network analysis helps to forward and control the project. Networks analysis provides the techniques for planning, scheduling, controlling etc.

Network analysis aims mainly at

1. Reducing the total cost of the project
2. Reducing the total time required to complete the project
3. Minimising idle resources
4. Minimising project delays and conflicts.

ACTIVITY AND EVENT

Activities are tasks which are parts of a project. They consume time and resources. Activity is the job or work required to materialise a specific objective. Activity is represented by an arrow whose tail represents the beginning and head represents the end.



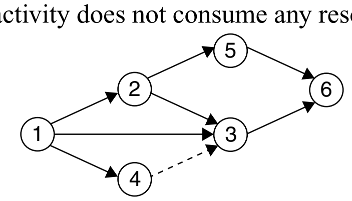
Activity (1 – 2)

It is the actual performance of the task.

DUMMY ACTIVITY

There are certain situations where one activity cannot be started until a previous activity is completed. There exists a proper precedence relationship between these activities. This relationship is shown by a dummy activity.

Dummy activity does not consume any resource or time.



In the figure shown, there is no activity 4 – 3, but it shows that 3 – 6 can be started after the completion of 1 – 4. Here, a precedence relation is established.

Events

Event is the instant in time when an activity is started or completed. An event represents the start and completion of an activity. In a network, event or node is the junction of two or more arrows representing activities. Event is a point in time and it does not consume any resource.

Events are represented by circles and activities by arrows.

Activity and Event Times

The following time factors are defined in networks.

1. **Earliest start time [EST]:**
   It is the earliest time at which the activity can be started. It is actually the earliest start time of the tail event.
2. **Earliest finish time [EFT]:**
   It is the earliest time at which the job can be finished.
   ∴ EFT = EST + duration of the job.
3. **Latest finish time [EFT]:**
   Latest finish time is the latest time in which a job can be completed without delaying the completion of the project. It is actually the latest expected time at the head event. It is the time beyond which the job cannot be delayed.
4. **Latest start time:**
   It is the latest time at which a job can be started with out delaying the project.
   LST = LFT – duration of the job activity.

Network Diagrams

A project is broken down in to well defined activities. The beginning or end of each activity is an event. A graph drawn connecting the various activities and events is known as a net work diagram. Each event is represented by a circle called 'node' and each activity by an arrow. Network diagrams can be of two types:

1. Event oriented diagram
2. Activity oriented diagram.

An event oriented network diagram is known as a PERT network diagram. Emphasis is given to the events of the project. The events are arranged in a logical sequence.

An activity oriented diagram is known as a CPM network diagram. Here, emphasis is given to the activities and the activities are arranged in a logical sequence.

However, the network diagrams will include events and activities regardless of whether they are event-oriented or activity-oriented.

Rules for Constructing Network Diagrams

1. Only one activity may connect any two nodes.
2. In the network, every activity is represented by one and only one arrow.
3. Other than the nodes, at the beginning and end of the network, all the other nodes will have at least one activity preceding it and at least one activity succeeding it.

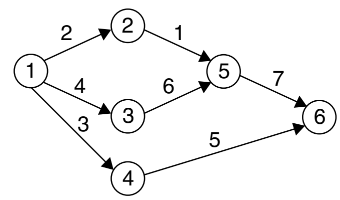
For eg., draw a network for the following details:

Duration	2	4	3	1	6	5	7
Activity	1– 2	1– 3	1– 4	2– 5	3– 5	4– 6	5– 6

Kindly note that the length of the arrow is not proportional to the duration of the activity. The diagram can be drawn step by step as follows:

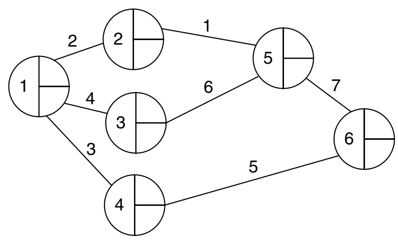
Step 1: Make a rough diagram representing the nodes by circles and activities by arrows and see how the network will look like. The nodes are numbered 1, 2, 3 -------. Write the duration of activities above or below the arrows:

(a)



Step 2: Re – draw the network neatly giving provisions at the node to enter EST, LST, EFT, LFT.

(b)



Step 3: Enter the time values as follows:

Consider node 1. Enter EST as zero. The earliest start time of the other nodes starting from 1 can be found by adding the activity time to zero.

Thus, EST of 2 is 2
EST of 3 is 4
EST of 4 is 3.

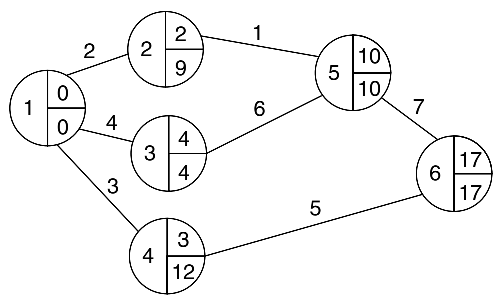
Now, consider the event 5. Event 5 has two approaches along 2 – 5 or along 3 – 5. The start time of event '5' shall be the maximum between that along 2 – 5 and 3 – 5. Along 2 –5, it is 2 + 1 = 3, along 3 – 5, it is 4 + 6 = 10. We should put 10 as the earliest start time for activity 5. Again, there are two approaches to '6'. One along 5 – 6, and the other along 4 – 6. The earliest start of the event '6' is the maximum along 5 – 6 or 4 – 6. Along 4 – 6, it is 3 + 5 = 8 and along 5 – 6, it is 10 + 7 = 17. We should put the maximum 17, as the earliest start of any event from 6. To retrace the path, start from '6'. The late start time for 4 – 6 is 17 – 5 = 12.

Similarly, the late start time for activity 5 – 6 is 17 – 7 = 10; the late start time for the activity 3 – 5 is 10 – 6 = 4;
the late start time for activity 2 – 5 is 10 – 1 = 9.

For the event 1, there are many approaches towards it.

The least time is entered as the late start time for the activity starting from event 1, that is, zero. In this case, all along the approaches, LST of 1 is zero.

(c)



Slack and Float

Slack is the term associated with an event. It shows the flexibility range that the event can avail. Slack is actually the difference between the earliest event time and the latest event time. But, float is associated with the activity. It is the range in which the activity start time and the activity finish time can fluctuate, without affecting the completion of the project.

Two important classifications of float are:

1. Total float
2. Free float.

Total float is the time by which the starting or finishing of an activity can be delayed without affecting the duration of the project. In most of the cases, there is a difference between the maximum time available, and the actual time required to perform an activity. This difference is evaluated as

Total float = LFT – EFT
= LST – EST.

Free float is a part of the total float that can be used by an activity without delaying the succeeding activity. Therefore, free float is given by the expression,

Free float = the difference between the earliest finish time of an activity and the earliest start time of the succeeding activity to

Free float = EST of succeeding activity – EFT of the present activity.

An activity is said to be critical if float is zero. That means, any delay for the critical activity will affect the project duration.

Critical Path and Critical Path Method (CPM)

The total time of a project is actually the maximum time elapsed along all the paths starting from the initial event and terminating at the final event.

Therefore, critical path is the sequence of activities which determines the completion time of the project indirectly. It is possible to have different paths from the starting point and reaching the terminal point. Among the different paths, the path which is time – wise longest is the critical path. All the activities along the critical path are critical activities.

Critical Path Method (CPM) is a network technique by which the following management functions can be executed:

1. Planning of the sequence of activities
2. Scheduling the time and resources
3. Controlling the performance so that it does not deviate from the plan.

CPM is generally used in repetitive type of projects. It is effective where fairly accurate measure of times for the completion of activities are known. Analysis of a project in CPM involves the following steps:

1. List all the activities
2. Draw the network
3. Calculate the earliest event time and latest event time
4. Calculate the earliest start time, latest start time, earliest finish time, latest finish time of all the activities.
5. Calculate the float for each activity
6. Identify the critical activities and critical path
7. Represent the critical path by double lines.

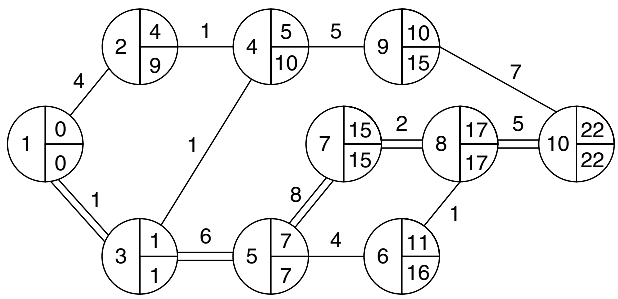
Solved Examples

Example 1: A project schedule is given as follows:

Duration	4	1	1	1	6	5
Activity	1 – 2	1 – 3	2 – 4	3 – 4	3 – 5	4 – 9
Duration	4	8	1	2	5	7
Activity	5 – 6	5 – 7	6 – 8	7 – 8	8 –10	9 – 10

The length of the critical path is
(A) 28 days (B) 22 days
(C) 17 days (D) 15 days.

Solution:
Based on the data given, draw the network.



Fill in the time values moving forward from 1 to 10. If there are two or more approaches to a node, the maximum time must be entered to the node (time must be considered along all the alternate routes).

While coming backwards, if there are more than one approaches to a node, the least time value which ever be the route must be entered to the bottom compartment of the node.

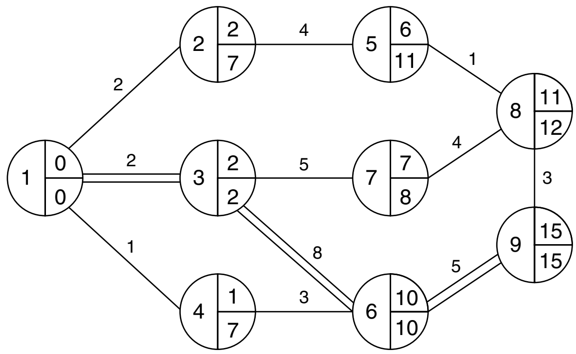
The critical path is
1 – 3 – 5 – 7 – 8 – 10.
The total duration is
1 + 6 + 8 + 2 + 5 = 22 days.

Example 2: The schedule of a project is given below.

Duration	2	2	1	4	8	5
Activity	1 – 2	1 – 3	1 – 4	2 – 5	3 – 6	3 – 7
Duration	3	1	5	4	3	
Activity	4 – 6	5 – 8	6 – 9	7 – 8	8 – 9	

The duration of the critical path is
(A) 15 months (B) 22 months
(C) 28 months (D) 30 months.

Solution:



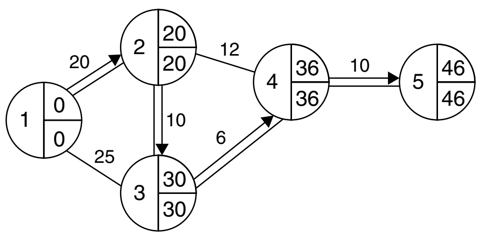
Critical path is 1 – 3 – 6 – 9.
Project duration is 15 months.

Direction for questions 3 and 4: The activities for a construction project is as given below:

Duration (weeks)	20	25	10	12	6	10
Activity	1 – 2	1 – 3	2 – 3	2 – 4	3– 4	4 – 5

Example 3: The duration of the project is
(A) 32 (B) 36
(C) 40 (D) 46.

Solution:



Critical path is 1 – 2 –3 – 4 –5, duration of the project = 46 weeks.

Example 4: The total float of the activity 2 – 4 is
(A) zero (B) 4 weeks
(C) 6 weeks (D) 8 weeks.

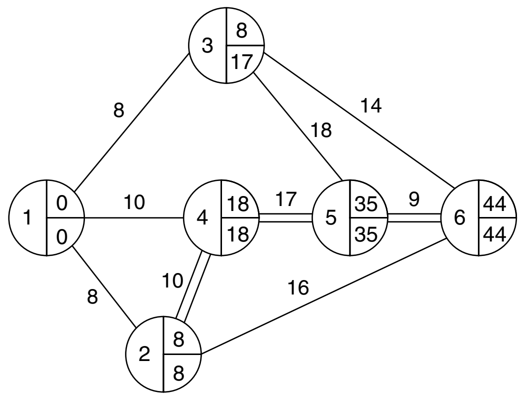
Solution:
Duration of the activity = 12 weeks.
The available duration is
= 36 – 20 = 16 weeks.
∴ Float = 16 – 12 = 4 weeks.

Direction for questions 5 and 6: A construction project's details are shown below. Duration of the activities is in weeks.

Duration (weeks)	8	8	10	10	16
Task	1 – 2	1 – 3	1 – 4	2 – 4	2 – 6
Duration (weeks)	18	17	14	9	
Task	3 – 5	4 – 5	3 – 6	5 – 6	

Example 5: Duration of the project is
(A) 44 weeks (B) 35 weeks
(C) 30 weeks (D) 30 weeks.

Solution:
The critical path is 1 – 2 – 4 – 5 – 6.
Total duration:
Length of project
= (duration along the critical path)
= 8 + 10 + 17 + 9 = 44 weeks.



Example 6: The total float of the activity 3 – 5 is
(A) 17 (B) 20 (C) 9 (D) 6.

Solution:
Allowable time for the activity is 35 – 8 = 27
Actual duration of activity = 18
Float = 27 – 18 = 9 weeks.

Program Evaluation and Review Technique (PERT)

PERT is a network technique which uses a network diagram consisting of events. Successive events are joined by arrows.

The main application of PERT network is where precise time measurement cannot be made. It is often used for non – repetitive type of projects.

PERT network is mainly used to find out whether a project could be completed by a given date. It also shows how a project can be completed earlier than the scheduled date.

Time Estimates

In PERT calculations, the time estimates are made by a probabilistic approach.

For each activity, there are three time estimates:

1. Optimistic time (t_o)
2. Pessimistic time (t_p)
3. Most likely time (t_m).

The expected time of completion of an activity is evaluated by the formula $t_e = \dfrac{t_o + 4t_m + t_p}{6}$

Optimistic time is the shortest time in which an activity can be completed under ideal conditions. This is the time in which the activity can be performed if everything goes in favour, with no problem or adverse condition.

Pessimistic time is the maximum time that would be taken to complete an activity. It is the time that might be taken to complete the activity when everything goes wrong.

Most likely time is the time that may be required at most of the occasions. It lies between optimistic and pessimistic time estimates.

The variance of an activity is given by $\left(\frac{t_p - t_o}{6}\right)^2$

The variance of the project duration is the sum of the variances of time estimates of all activities along the critical path.

The probability of finishing the project on some target date is found using the standard normal table.

$$z = \frac{X - \mu}{\sigma}$$

$$= \frac{\text{due date} - \text{expected time of completion}}{\sigma}$$

where, σ = standard deviation

$$\text{i.e. } \sigma = \sqrt{\text{variance}} = \sqrt{\sum\left(\frac{t_p - t_o}{6}\right)^2}$$

Direction for questions 7 and 8: A project schedule is given below:

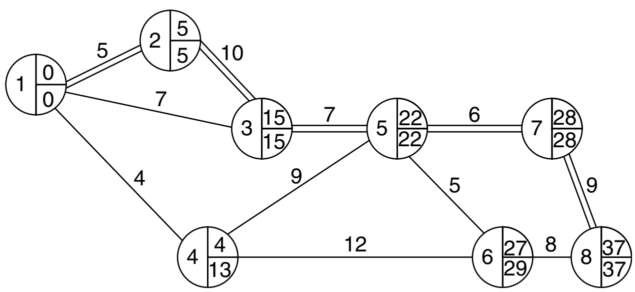
	1 – 2	1 – 3	2 – 3	1 – 4	3 – 5	4 – 5	4 – 6	5 – 7	5 – 6	6 – 8	7 – 8
Job	A	B	C	D	E	F	G	H	I	J	K
Least time	4	5	8	2	4	7	8	4	3	5	6
Greatest time	6	9	12	6	10	15	16	8	7	11	12
Most likely time	5	7	10	4	7	8	12	6	5	8	9

Example 7: The project duration is

(A) 35 weeks (B) 37 weeks
(C) 40 weeks (D) 42 weeks.

Solution:

From the data, a network can be drawn first.



Expected time for each activity can be found using the formula $t_e = \frac{t_o + 4t_m + t_p}{6}$

Job	t_o	t_m	t_p	t_e	Job	t_o	t_m	t_p	t_e
1–2	4	5	6	5	4–6	8	12	16	12
1–3	5	7	9	7	5–7	4	6	8	6
2–3	8	10	12	10	5–6	3	5	7	5
1–4	2	4	6	4	6–8	5	8	11	8
3–5	4	7	10	7	7–8	6	9	12	9
4–5	7	8	15	9					

The critical path is 1 – 2 – 3 – 5 – 7 – 8, project duration is 37.

Example 8: The total float of the activity 4 – 5 is

(A) 8 (B) 12 (C) 9 (D) 7.

Solution:

Available time for the activity
= 22 – 4 = 18.

Actual duration of the activity = 9

∴ Total float = 18 – 9 = 9 weeks.

Direction for questions 9 and 10: The activity and time distribution for a project is as shown below.

Activity	1–2	1–3	2–4	3–4	4–5	3–5
Optimistic time	2	9	5	2	6	8
Most likely time	5	12	14	5	9	17
Pessimistic time	14	15	17	8	12	20

Example 9: The critical paths are

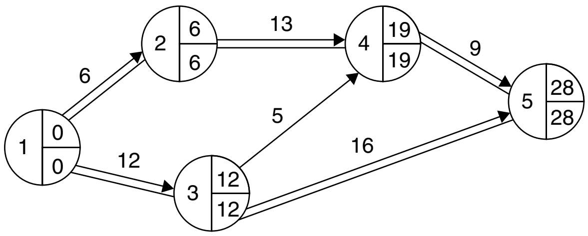
(A) 1 – 3 – 4 – 5 and 1 – 2 – 4 – 5
(B) 1 – 3 – 5 and 1 – 2 – 4 – 5
(C) 1 – 3 – 2 – 5 and 1 – 4 – 5
(D) 1 – 2 – 3 – 5 and 1 – 4 – 5.

Solution:

Evaluating the expected time for the activities by using the formula

$$t_e = \frac{t_o + 4t_m + t_p}{4}$$

Activity	Expected time
1 – 2	6
1 – 3	12
2 – 4	13
3 – 4	5
4 – 5	9
3 – 5	16



There are two critical paths.
They are 1 – 2 – 4 – 5 and 1 – 3 – 5.

Example 10: The total float for the activity 3 – 4 is
(A) 2 weeks (B) 3 weeks
(C) 4 week (D) 5 weeks.

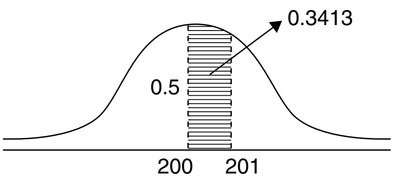
Solution:
The available time for the activity 3 – 4 is 19 – 12 = 7 weeks.
The actual duration of the activity = 5 weeks.
∴ Total float = 7 – 5 = 2 weeks.

Example 11: The mean and standard deviation of the duration of a project are 250 days and 50 days respectively. The probability of completing the project in 300 days is
(A) 0.62 (B) 0.71 (C) 0.74 (D) 0.84.

Solution:
The estimated duration of the project is 250 days and the standard deviation is 50 days.

∴ Standard normal variable $z = \frac{x-\mu}{\sigma} = \frac{300-250}{50} \Rightarrow z = 1.$

Corresponding to $z = 1$, the area under the standard normal curve is = 0.5 + 0.3413 = 0.8413.



∴ the required probability is = 0.84.

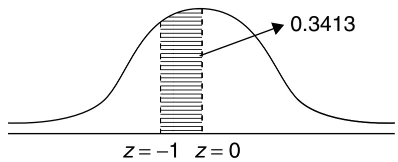
Direction for questions 12 and 13: The expected time of competition of a project is 18 months with a standard deviation of 3 months.

Example 12: If the due date of the project is fixed as 15 months, the probability that the project will be completed in the due date is
(A) 0.2 (B) 0.19 (C) 0.16 (D) 0.13.

Solution:
Expected time $\mu = 18$ months.
The due date is 15 months.
Standard normal variable

$$Z = \frac{15-18}{3} = \frac{-3}{3} = -1$$

When $Z = -1$,



required probability is the patched area.
That is, 0.5 – 0.3413 = 0.1587
= 0.16.
The require probability is 0.16.

Example 13: The number of days within which the project will be completed with a probability of 87.9% is
(A) 19.5 days (B) 21.5 days
(C) 23.2 days (D) 25.8 days.

Solution:
The given probability is 0.879. That is,

0.5 + 0.379

z value corresponding to the area

0.379 = 1.17

$$\frac{D-18}{3} = (Z \text{ value of } 0.379) = 1.17$$

$$\frac{D-18}{3} = 1.17; D = 18 + 3.51$$

$$= 21.51 \text{ days.}$$

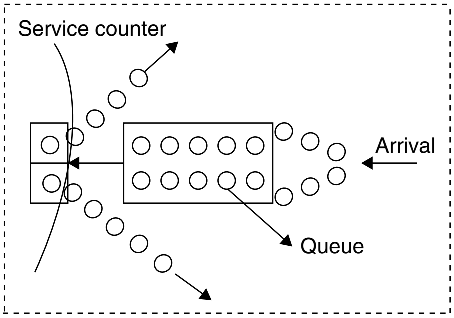
Queuing Theory

A group of people or items waiting to receive a service is known as a waiting line or queue. It is very difficult to predict the arrival and the type of service facility to be provided.

If too much facilities of service are provided, it results in unnecessary cost and idling of facility. On the other hand, if we do not provide adequate service capacity, it may lead to a long waiting line which again will incur cost to the organisation indirectly.

So, it is required to strike an economic balance between the cost of service and the cost associated with waiting for the services.

Queuing theory is an engineering technique by which we can optimise the provision of service facility so that cost is minimised and customer satisfaction is maintained. We can construct mathematical models for various types of queuing systems.



Some Definitions

1. Queue or waiting line: This represents the number of persons waiting to be served. The queue does not include the customer being served.
2. Arrival rate: This is the rate at which the customers arrive to be served. Arrival rate is not a constant; therefore, it is assumed to be a random variable for which certain probability distribution can be assumed. In queuing theory, it is assumed that the arrival rate is randomly distributed according to Poisson's distribution. The mean value of the arrival rate is usually denoted as 'λ', the unit being customers/unit time.
3. Service rate: This is the rate at which a service is offered to the customers. This can be given by a single server or sometimes by multiple servers. But 'service rate' is referred to the service offered by a single channel of the service. This rate is also a random variable and therefore, it follows a probability distribution. It is also assumed to be following Poisson's distribution. The service rate is represented as 'μ'.

Traffic Density

Traffic density or system utilisation is defined as the ratio of the arrival rate to the service rate.

It is usually denoted as

$$\rho = \lambda/\mu.$$

Expected Number in the Queue

It is the average or mean number of customers waiting to be serviced. It is denoted as Lq.

Expected Time in the Queue

It is the average time a customer is waiting in the queue, it is denoted as Wq.

Expected Time in the System

It is the average time a customer is waiting in the queue and/or being serviced. It is denoted by *W*.

Important Formulae in Queuing Theory

1. The probability of an empty queue
   $Po = 1 - \lambda/\mu$.
2. Probability of having at least 'n' customers in the system $Pn = \left(\dfrac{\lambda}{\mu}\right)^n$
3. The expected number of customers in service = traffic density = λ/μ.
4. Expected number of people in a system $L = \dfrac{\lambda}{\mu - \lambda}$
5. Expected number of customers in the queue

$$= L_q = \frac{\lambda}{\mu - \lambda} - \frac{\lambda}{\mu}$$

$$= \frac{\lambda\mu - \lambda\mu + \lambda^2}{\mu(\mu - \lambda)}$$

$$= \frac{\lambda^2}{\mu(\mu - \lambda)}$$

6. Expected waiting time in the system

$$W = \frac{1}{\mu - \lambda}$$

7. Expected waiting time in the queue =

$$Wq = \frac{\lambda}{\mu(\mu - \lambda)}$$

8. Average length of non – empty queue = $\dfrac{\mu}{\mu - \lambda}$

Example 14: A single-machine shop receives customers at the rate of 4/hr for repairing an electrical appliance. The mechanic operates the machines and repairs the appliances on an average in 6 minutes. Then the average number of customers in the system is

(A) $\frac{2}{3}$ (B) $\frac{3}{4}$ (C) $\frac{1}{2}$ (D) $\frac{1}{4}$

Solution:

$\lambda = 4$/hr, $\mu = 6$ min/repair $= \dfrac{1}{6}$ repair/min

$\mu = \dfrac{1}{6} \times 60$ repair/hr = 10 repair/hr.

Traffic density $= \dfrac{\lambda}{\mu} = \dfrac{4}{10} = 0.4$.

The average number of customers in the system

$$= \frac{\lambda}{\mu - \lambda} = \frac{4}{10 - 4}$$

$$= \frac{4}{6} = \frac{2}{3}$$

Direction for questions 15 and 16: In a car washing yard, cars arrive at a rate of 30 cars/day. The washing takes place such that the average washing time is 36 min/car.

Example 15: Then, the average length of the queue is

(A) 8 cars (B) 6 cars (C) 4 cars (D) 2 cars.

Solution:

$$\text{Arrival rate } \lambda = \frac{30}{\text{day}}$$

$$\text{Service rate} = \frac{36 \text{ min}}{\text{car}}$$

$$\mu = \frac{1}{36} \text{car/mt}$$

$$\text{Arrival rate } \lambda = \frac{30}{24 \times 60} = \frac{1}{48} \text{ car/mt}$$

Average length of the queue,

$$\frac{\mu}{\mu - \lambda} = \frac{\frac{1}{36}}{\frac{1}{36} - \frac{1}{48}}$$

$$= \frac{\frac{1}{3}}{\frac{1}{3} - \frac{1}{4}} = \frac{12}{3} = 4 \text{ cars.}$$

Example 16: Probability that the queue size exceeds 10 is

(A) $\left(\frac{1}{4}\right)^{10}$ (B) $\left(\frac{3}{4}\right)^{11}$ (C) $\left(\frac{1}{2}\right)^{11}$ (D) $\left(\frac{1}{3}\right)^{10}$

Solution:

Probability that the queue size exceeds 10 $= P(n > 10) = P(11)$

$$= \left(\frac{\lambda}{\mu}\right)^{11}$$

$$= \frac{\lambda}{\mu} = \frac{\frac{1}{48}}{\frac{1}{36}} = \frac{36}{48} = \frac{3}{4}$$

$$= \left(\frac{3}{4}\right)^{11}$$

Example 17: In a bank, one customer arrives for cashing a cheque in every 15 minutes. The staff in the only payment counter takes 10 minutes for serving the customers on an average. Then the average queue length is

(A) 6 (B) 5 (C) 4 (D) 3.

Solution:

$$\text{Arrival rate } \lambda = \frac{1}{5} \text{ per min.}$$

$$\text{Service rate } \mu = \frac{1}{10} \text{ per min.}$$

$$\text{Average length of the queue} = \frac{\mu}{\mu - \lambda} = \frac{\frac{1}{10}}{\frac{1}{10} - \frac{1}{15}}$$

$$\frac{1}{2} \times 6 = 3 \text{ customers.}$$

Exercises

Practice Problems I

1. Which of the following statements is correct?
   (A) an event does not consume any resources
   (B) events and activities consume resources
   (C) events and activities are one and the same
   (D) an event is represented by an arrow

2. PERT network is
   (A) an activity oriented network
   (B) an event oriented network
   (C) an activity or event oriented network
   (D) it is a review network.

3. Float is the term associated with
   (A) activity
   (B) event
   (C) event or activity
   (D) exact time of competition of an activity.

4. Along the critical path of a project
   (A) the total float will be zero
   (B) the standard deviation will be minimum
   (C) activities of maximum duration will be aligned
   (D) the slack of the events will be minimum.

5. The expected time of completion of an activity in PERT networks, where t_o is the optimistic time, t_p the pessimistic time and t_m the most likely time is given by
   (A) $t_e = \frac{t_o + 4t_m + t_p}{4}$
   (B) $t_e = \frac{t_o + 4t_m + t_p}{2}$
   (C) $t_2 = \frac{t_o + t_m + t_p}{3}$
   (D) $te = \frac{t_o + 4t_m + t_p}{6}$

6. In a PERT network, the optimistic and pessimistic time are equal. The most likely time and expected time are 1 week each. Then, the optimistic time is
(A) 1 week (B) 2 weeks
(C) 3 weeks (D) 4 weeks.

Direction for questions 7 to 9: Activities and estimated durations of a project are given in the following chart:

Activity	Time estimates (days)		
	Optimistic	Most likely	Pessimistic
1 – 2	1	1	7
1 – 3	1	4	7
1 – 4	2	2	8
2 – 5	1	1	1
3 – 5	2	5	14
4 – 6	2	5	8
5 – 6	3	6	15

7. The expected duration of the project is
(A) 22 days (B) 17 days
(C) 14 days (D) 15 days.

8. The standard deviation along the critical path is
(A) 3 days (B) 5 days
(C) 6 days (D) 8 days.

9. The probability that the project will be completed on the scheduled date is
(A) 50% (B) 12.2%
(C) 15.9% (D) 22.3%.

10. Which of the following statements is correct?
(A) PERT is a deterministic model
(B) CPM is used for activities where the duration is uncertain
(C) CPM is usually used for repetitive jobs
(D) In PERT, time is the controlling factor

11. PERT calculations give the following information. The length of a project is 40 days with a variance along the critical path equal to 25. The number of days within which we can expect the project to be completed with 99.99% probability is
(A) 39 days (B) 65 days
(C) 34 day (D) 30 days.

Direction for questions 12 and 15: The following table gives the details of a project. The unit of duration of the activities is months. The variations of time are expected to follow normal probability distribution. Expected cost of each activity is also given.

Activity	Expected time (months)	Variance	Cost ₹1000
1 – 2	4	1	5
2 – 3	2	1	3
3 – 6	3	1	4
2 – 4	6	2	9
1 – 5	2	1	2
5 – 6	5	1	12
4 – 6	9	5	20
5 – 7	7	8	7
7 – 8	10	16	14
6 – 8	1	1	4

12. The expected time to complete the project.
(A) 26 months (B) 24 months
(C) 22 months (D) 20 months.

13. Standard deviation along the critical path is
(A) 5 (B) 4
(C) 3 (D) 1.

14. The expected cost of the project is
(A) ₹38,000 (B) ₹42,000
(C) ₹62,000 (D) ₹80,000.

15. The total float of the activity 3 – 6 is
(A) 7 months (B) 9 months
(C) 10 months (D) 11 months.

16. Number of customers in the queue system means
(A) no. of customers in the queue waiting for the service
(B) no. of customers being served at the service centre
(C) no. of customers waiting for the service and the number of customers being served
(D) the expected number of customers in the queue.

Direction for questions 17 and 18: Customers arrive at one counter of a bank according to Poisson's distribution with an average rate of 10 persons/hour. The service time for the customers is evaluated to be exponentially distributed with a mean time of 5 minutes/customer. The space in front of the counter can accommodate only 3 customers including the man who is being served. Others are to wait outside the space.

17. The probability that a customer arriving has to wait outside the space is
(A) 0.53 (B) 0.48
(C) 0.42 (D) 0.36.

18. The average time the customers are expected to wait before being served is
(A) 15 min (B) 20 min
(C) 25 min (D) 29 min.

Direction for questions 19 and 20: In a bank, a customer arrives for encashing the cheque in every 20 minutes. The only staff in the counter takes 15 minutes to serve the customers, on an average.

19. The average queue length is
(A) 2.25 units (B) 2.75 units
(C) 3.25 units (D) 3.75 units.

20. The average waiting time for the system is
(A) 20 min (B) 25 min
(C) 30 min (D) 60 min.

Practice Problems 2

1. Dummy activity
   (A) is one which consumes time and resources and indicates precedence
   (B) is one which does not consume time or resources and indicates precedence
   (C) is an event only
   (D) can replace a real activity.
2. Which of the following statements is correct?
   (A) Events are represented by circles and activities by arrows
   (B) Events are represented by arrows and activities by circles
   (C) Events and activities are represented by arrows
   (D) Circles indicates event or activity.
3. Free float of an activity in an event is
   (A) EST of successor – LFT present event
   (B) EST of successor – EFT present event
   (C) EFT of the present event – EST of the present event
   (D) LST of the present event – EST of the present event.
4. Total float of an activity is given as
   (A) LST – EFT
   (B) LFT – EST
   (C) LFT – EFT
   (D) sum of the floats of all activities.
5. A project network is given as follows:

Job Name	a	b	c	d	e	f
Immediate predecessor			a, b	a	d	c, e
Time to complete (days)	10	3	4	7	4	12

   The duration of the project (in days) is
   (A) 17 (B) 21
   (C) 30 (D) 33.

Direction for questions 6 to 8: The following table gives the activities of a construction project and their duration in days:

Activity	Duration
1 – 2	20
1 – 3	25
2 – 3	10
2 – 4	12
3 – 4	6
4 – 5	10

6. The critical path of the project is
   (A) 1 – 2 – 3 – 4 – 5 (B) 1 – 3 – 4 – 5
   (C) 1 – 2 – 4 – 5 (D) 1 – 3 – 2 – 4 – 5.
7. The duration of the project is
   (A) 42 days (B) 43 days
   (C) 46 days (D) 49 days.
8. The total float of the activity 2 – 4 is
   (A) 3 days (B) 4 days
   (C) 5 days (D) 6 days.

Direction for questions 9 and 11: Consider the details of the PERT network given below.

Activity	t_o	t_m	t_p
1 – 2	1	1	7
1 – 3	1	4	7
1 – 4	2	2	8
2 – 5	1	1	1
3 – 5	2	5	14
4 – 6	2	5	8
5 – 6	3	6	15

9. The duration of the project is
   (A) 22 days (B) 17 days
   (C) 19 days (D) 18 days.
10. The standard duration along the critical path is
   (A) 3 days (B) 4 days
   (C) 5 days (D) 6 days.
11. The total float of the activity 4 – 6 is
   (A) 6 days (B) 9 days
   (C) 12 days (D) 13 days.

Direction for questions 12 to 16: The following table lists the jobs of a network with their time estimates.

Job	Duration (days)		
	Optimistic	Most likely	Pessimistic
1 – 2	3	6	15
1 – 6	2	5	14
2 – 3	6	12	30
2 – 4	2	5	8
3 – 5	5	11	17
4 – 5	3	6	15
6 – 7	3	9	27
5 – 8	1	4	7
7 – 8	4	19	28

12. The length of the critical path is
   (A) 27 days (B) 32 days
   (C) 35 days (D) 36 days.
13. The standard deviation of the critical path is
   (A) 3 days (B) 4 days
   (C) 5 days (D) 6 days.
14. The total float of the activity 7 – 8 is
   (A) 1 day (B) 2 days
   (C) 3 days (D) 4 days.
15. The probability that the job will be completed in 42 days is

(A) 0.67 (B) 0.72
(C) 0.88 (D) 0.92.

16. The mean project duration and standard deviation along the critical path of a project are 85 days and 18 days respectively. The probability that the project will be completed in 75 days is
(A) 0.29 (B) 0.32 (C) 0.41 (D) 0.48.

Direction for questions 17 and 18: PERT calculation of a project gives the following information: Project length is 60 weeks with a variance of 9 weeks.

17. The expected number of weeks within which the project can be completed with 95% probability is
(A) 71 weeks (B) 68 weeks
(C) 65 weeks (D) 56 weeks.

18. The number of weeks that can be expected within which the project will be completed with 42% probability is
(A) 59.4 weeks (B) 57.6 weeks
(C) 57.2 weeks (D) 55.8 weeks.

Direction for questions 19 and 20: PERT evaluation of a project reveals that the estimated completion date of the project is 380 days with a variance of 196 days.

19. With 60% probability, we can expect the project to be completed in
(A) 360 days (B) 384 days
(C) 392 days (D) 402 days.

20. The probability that the project will be completed in 360 days is
(A) 0.14 (B) 0.12
(C) 0.09 (D) 0.08.

21. A queuing model specified as (M/M/1: ∞ FIFO) has an arrival rate variation
(A) according to Poisson's distribution
(B) according to exponential distribution
(C) according to γ – distribution
(D) according to hyper-geometric distribution.

22. By the application of queuing theory the management can
(A) minimise the total waiting time and service costs
(B) estimate the waiting time and service cost
(C) optimise the existing system
(D) improve the productivity.

23. If in a service station, vehicles arrive at the rate of 5 nos./hour and the servicing time per vehicle is 10 minutes, Then the traffic intensity is
(A) 1.2 (B) 0.83
(C) 0.6 (D) 0.72.

Direction for questions 24 and 25: In a marshalling yard, goods trains arrive at a rate of 20 trains/day. The inter – arrival time follows exponential distribution, and the service time distribution is also exponential. The average time of service/train is 42 minutes.

24. Then, the probability that the queue size exceeds 8 is
(A) 0.085 (B) 0.062
(C) 0.042 (D) 0.013.

25. The probability of an empty queue is
(A) $\frac{3}{2}$ (B) $\frac{5}{12}$
(C) $\frac{11}{12}$ (D) $\frac{13}{17}$.

Direction for questions 26 and 27: In a loading station, lorries arrive at a rate of 10 per shift. Loading takes place at a rate of 12 nos./shift.

26. Then, the average number of lorries that can be expected in the system is
(A) 2 nos. (B) 3 nos.
(C) 4 nos. (D) 5 nos.

27. The average waiting time in the system is
(A) 1.5 min (B) 1 min
(C) 0.5 min (D) 0.25 min.

28. In a booking office, which is manned by a single individual, customers arrive at a rate of 30 per hour. The time required to serve the customers has exponential distribution with a mean of 120 seconds. The average waiting time for a customer is
(A) 5 min (B) 8.2 min
(C) 9 min (D) 0 min.

Direction for questions 29 and 30: Arrivals at a telephone booth are considered to be in accordance with the Poisson distribution, with an average time of 10 min between consecutive arrivals. The length of the phone calls is exponentially distributed with a mean of 3 minutes.

29. The probability that a person arriving at the booth has to wait is
(A) 0.5 (B) 0.3
(C) 0.2 (D) 0.1.

30. The expected length of a non – empty queue is
(A) $\frac{3}{7}$ (B) $\frac{5}{7}$
(C) $\frac{9}{7}$ (D) $\frac{4}{7}$

Previous Years' Questions

1. In PERT analysis, a critical activity has **[2004]**
(A) maximum float (B) zero float
(C) maximum cost (D) minimum cost.

2. A maintenance service facility has Poisson arrival rates, negative exponential service time and operates on a 'first come first served' queue discipline. Breakdown occurs on an average of 3 per day with a range of zero to eight. The maintenance crew can service an average of 6 machines per day with a range of zero to seven.

The mean waiting time for an item to be serviced would be **[2004]**

(A) $\frac{1}{6}$ day (B) $\frac{1}{3}$ day
(C) 1 day (D) 3 days.

3. Consider a single server queuing model with Poisson arrivals (λ = 4/hour) and exponential service (μ = 4/hour). The number in the system is restricted to a maximum of 10. The probability that a person who comes in, leaves without joining the queue is **[2005]**

(A) $\frac{1}{11}$ (B) $\frac{1}{10}$ (C) $\frac{1}{9}$ (D) $\frac{1}{2}$

4. A project has six activities (A to F) with respective activity durations of 7, 5, 6, 6, 8, 4 days. The network has three paths: A-B, C-D and E-F. All the activities can be crashed with the same crash cost per day. The number of activities that need to be crashed to reduce the project duration by 1 day is **[2005]**
(A) 1 (B) 2 (C) 3 (D) 6.

5. The number of customers arriving at a railway reservation counter is Poisson distributed with an arrival rate of eight customers per hour. The reservation clerk at this counter takes six minutes per customer on an average, with an exponentially distributed service time. The average number of the customers in the queue will be **[2006]**

(A) 3 (B) 3.2 (C) 4 (D) 4.2.

Direction for questions 6 and 7: Consider a PERT network for a project involving six tasks (a to f):

Task	Predecessor	Expected task time (in days)	Variance of the task time (in days)
a	-	30	25
b	a	40	64
c	a	60	81
d	b	25	9
e	b, c	45	36
f	d, e	20	9

6. The expected completion time of the project is **[2006]**
(A) 238 days (B) 224 days
(C) 171 days (D) 155 days.

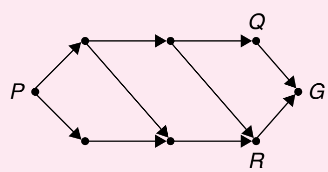
7. Standard deviation of the critical path of the project is **[2006]**

(A) $\sqrt{151}$ days (B) $\sqrt{155}$ days
(C) $\sqrt{200}$ days (D) $\sqrt{238}$ days.

8. In an M/M/1 queuing system, the number of arrivals in an interval of length T is a Poisson random variable, i.e. the probability of there being n arrivals in an interval of length T is $\frac{e^{-\lambda T}(\lambda T)^n}{n!}$. The probability density functions $f(t)$ of the inter-arrival time is given by **[2008]**

(A) $\lambda^2 \left(e^{-\lambda^2 t}\right)$ (B) $\frac{e^{-\lambda^2 t}}{\lambda^2}$
(C) $\lambda e^{-\lambda t}$ (D) $\frac{e^{-\lambda t}}{\lambda}$

9. For the network below, the objective is to find the length of the shortest path from node P to node G. Let d_{ij} be the length of directed arc from node i to node j.



Let s_j be the length of the shortest path from P to j. Which of the following equations can be used to find S_G? **[2008]**

(A) $S_G = \text{Min}\{S_Q, S_R\}$

(B) $S_G = \text{Min}\{S_Q - d_{QG}, S_R - d_{RG}\}$

(C) $S_G = \text{Min}\{S_Q + d_{QR}, S_R + d_{RG}\}$

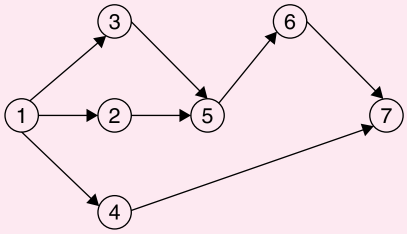
(D) $S_G = \text{Min}\{d_{QG}, d_{RG}\}$.

10. The expected time (t_e) of a PERT activity in terms of optimistic time (t_o), pessimistic time (t_p) and most likely time (t_l) is given by **[2009]**

(A) $t_e = \frac{t_o + 4t_l + t_p}{6}$ (B) $t_e = \frac{t_o + 4t_p + t_\ell}{6}$

(C) $t_e = \frac{t_o + 4t_\ell + t_p}{3}$ (D) $t_e = \frac{t_o + 4t_p + t_\ell}{3}$

Direction for questions 11 and 12: Consider the following PERT network:



The optimistic time, most likely time and pessimistic time of all the activities are given in the table below.

Activity	Optimistic time (days)	Most likely time (days)	Pessimistic time (days)
1-2	1	2	3
1-3	5	6	7
1-4	3	5	7
2-5	5	7	9
3-5	2	4	6
5-6	4	5	6
4-7	4	6	8
6-7	2	3	4

11. The critical path duration of the network (in days) is **[2009]**

(A) 11 (B) 14
(C) 17 (D) 18.

12. The standard deviation of the critical path is **[2009]**

(A) 0.33 (B) 0.55
(C) 0.77 (D) 1.66.

13. Little's law is the relationship between **[2010]**
(A) stock level and lead time in an inventory system
(B) waiting time and length of the queue in a queuing system
(C) number of machines and job due dates in a scheduling problem
(D) uncertainty in the activity time and project completion time.

14. The project activities, precedence relationships and durations are described in the table. The critical path of the project is **[2010]**

Activity	Precedence	Duration (in days)
P	–	3
Q	–	4
R	*P*	5
S	*Q*	5
T	*R, S*	7
U	*R, S*	5
V	*T*	2
W	*U*	10

(A) $P-R-T-V$ (B) $Q-S-T-V$
(C) $P-R-U-W$ (D) $Q-S-U-W$.

15. Cars arrive at a service station according to Poisson's distribution with a mean rate of 5 per hour. The service time per car is exponential with a mean of 10 minutes. At steady state, the average waiting time in the queue is **[2011]**
(A) 10 minutes (B) 20 minutes
(C) 25 minutes (D) 50 minutes.

Direction for questions 16 and 17: For a particular project, eight activities are to be carried out. Their relationships with other activities and expected durations are mentioned in the table below:

Activity	Predecessors	Duration (days)
a	–	3
b	a	4
c	a	5
d	a	4
e	b	2
f	d	9
g	c, e	6
h	f, g	2

16. The critical path of the project is **[2012]**
(A) a – b – e – g – h (B) a – c – g – h
(C) a – d – f – h (D) a – b – c – f – h.

17. If the duration of activity f alone is changed from 9 to 10 days, then the **[2012]**
(A) critical path remains the same and the total duration to complete the project changes to 19 days
(B) critical path and the total duration to complete the project remain the same
(C) critical path changes, but the total duration to complete the project remains the same
(D) critical path changes and the total duration to complete the project changes to 17 days.

18. Customers arrive at a ticket counter at a rate of 50 per hr and tickets are issued in the order of their arrival. The average time taken for issuing a ticket is 1 min. Assuming that customer arrivals form a Poisson process and service times are exponentially distributed, the average waiting time in queue in minutes is **[2013]**
(A) 3 (B) 4 (C) 5 (D) 6.

19. Jobs arrive at a facility for service, in a random manner. Probability distribution of the number of arrivals of jobs in a fixed time interval is **[2014]**
(A) Normal (B) Poisson
(C) Erlang (D) Beta.

20. Jobs arrive at a facility at an average rate of 5 in an 8 hour shift. The arrival of jobs follows Poisson distribution. The average service time of a job on the facility is 40 minutes. The service time follows exponential distribution. Idle time (in hours) at the facility per shift will be **[2014]**

(A) $\frac{5}{7}$ (B) $\frac{14}{3}$

(C) $\frac{7}{5}$ (D) $\frac{10}{3}$

21. A project has four activities P, Q, R and S as shown below: **[2014]**

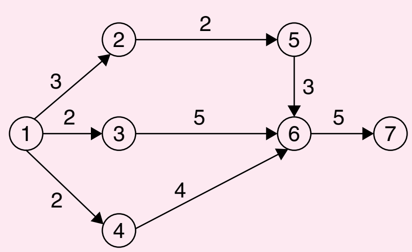
Activity	Normal duration (days)	Predecessor	Cost slope (₹/day)
P	3	–	500
Q	7	P	100
R	4	P	400
S	5	R	200

The normal cost of the project is ₹10000 and the overhead cost is ₹200 per day. If the project duration has to be crashed down to 9 days, the total cost (in Rupees) of the project is ______________

22. A minimal spanning tree in network flow models involves **[2014]**

(A) all the nodes with cycle/loop allowed
(B) all the nodes with cycle/loop not allowed
(C) shortest path between start and end nodes
(D) all the nodes with directed arcs.

23. Consider the given project network, where numbers along various activities represent the normal time. The free float on activity 4-6 and the project duration, respectively are **[2014]**



(A) 2, 13 (B) 0, 13
(C) –2, 13 (D) 2, 12.

24. The precedence relations and duration (in days) of the activities of a project network are given in the table. The total float (in days) of activities e and f, respectively are **[2014]**

Activity	Predecessors	Duration (days)
a	–	2
b	–	4
c	a	2
d	b	3
e	c	2
f	c	4
g	d, e	5

(A) 0 and 4 (B) 1 and 4
(C) 2 and 3 (D) 3 and 1.

25. At a work station, 5 jobs arrive every minute. The mean time spent on each job in the work station is 1/8 minute. The mean steady state number of jobs in the system is ______________ **[2014]**

26. Following data refers to the activities of a project, where, node 1 refers to the start and node 5 refers to the end of the project. **[2015]**

Activity	Duration (days)
1 – 2	2
2 – 3	1
4 – 3	3
1 – 4	3
2 – 5	3
3 – 5	2
4 – 5	4

The critical path (CP) in the network is

(A) 1–2–3–5 (B) 1–4–3–5
(C) 1–2–3–4–5 (D) 1–4–5

27. In the notation $(a/b/c)$:$(d/e/f)$ for summarizing the characteristics of queueing situation, the letters 'b' and 'd' stand respectively for: **[2015]**

(A) service time distribution and queue discipline.
(B) number of servers and size of calling source.
(C) number of servers and queue discipline.
(D) service time distribution and maximum number allowed in system.

28. In a single-channel queuing model, the customer arrival rate is 12 per hour and the serving rate is 24 per hour. The expected time that a customer is in queue is ______ minutes. **[2016]**

29. A project consists of 14 activities, A to N. The duration of these activities (in days) are shown in brackets on the network diagram. The latest finish time (in days) for node 10 is _______. **[2016]**

30. In PERT chart, the activity time distribution is: **[2016]**

(A) Normal (B) Binormal
(C) Poisson (D) Beta

Answer Keys

Exercises

Practice Problems 1

1. A	**2.** B	**3.** A	**4.** A	**5.** D	**6.** A	**7.** B	**8.** A	**9.** A	**10.** D
11. B	**12.** D	**13.** C	**14.** D	**15.** C	**16.** C	**17.** B	**18.** C	**19.** A	**20.** D

Practice Problems 2

1. B	**2.** A	**3.** A	**4.** C	**5.** D	**6.** A	**7.** C	**8.** B	**9.** B	**10.** A
11. B	**12.** D	**13.** C	**14.** A	**15.** C	**16.** A	**17.** C	**18.** A	**19.** B	**20.** D
21. A	**22.** B	**23.** B	**24.** D	**25.** B	**26.** D	**27.** C	**28.** D	**29.** B	**30.** A

Previous Years' Questions

1. B	**2.** A	**3.** A	**4.** C	**5.** B	**6.** D	**7.** A	**8.** C	**9.** C	**10.** A
11. D	**12.** none	**13.** B	**14.** D	**15.** D	**16.** C	**17.** A	**18.** C	**19.** B	**20.** B
21. 12490 to 12510		**22.** B	**23.** A	**24.** B	**25.** 1.62 to 1.7		**26.** B	**27.** B	**28.** 2.5
29. 14	**30.** D								

Test

Industrial Engineering

Time: 60 Minutes

Direction for questions 1 to 25: Select the correct alternative from the given choices.

1. Production planning means
(A) Producing according to the demand in the market
(B) Scheduling the production process effectively to avoid lapses
(C) Determining the human and material resources necessary to produce the output demanded
(D) A procedure to eliminate wastage of material.

2. In the context of manufacturing management, the function 'despatch' indicates
(A) Despatch of mails arriving in the factory
(B) Despatch of work orders through the shop floor
(C) Despatch of sales requirement
(D) Despatch of finished product to the stores.

3. System effectiveness is given by the ratio
(A) $\frac{\text{actual output}}{\text{actual input}}$ (B) $\frac{\text{actual output}}{\text{system capacity}}$
(C) $\frac{\text{actual output}}{\text{minimum input}}$ (D) $\frac{\text{system output}}{\text{system input}}$.

4. A firm has five numbers of work centres with their capacity/day as shown in the block diagram.

410 – 550 – 309 – 340 – 420 → 280

Then the system effectiveness is
(A) 190% (B) 50.9%
(C) 90.6% (D) 66.67%.

5. Therbligs are used in the study of
(A) Performance rating
(B) Time study with limited movement
(C) All types of motion study
(D) Micro motion study

6. The correct alternative is
(A) components of work study are method study and work measurement
(B) components of method study are work study and work measurement
(C) components of work measurements are work study and method study
(D) components of work measurements are method study and work analysis.

7. In an assembling job, the average time for an activity was found to be 13.20 min by a man whose performing rating is 105. The rest and personal allowances permitted was 10% of the standard time. The standard time of the activity is
(A) 16.8 min (B) 15.4 min
(C) 14.2 min (D) 13.8 min.

8. The fixed cost for a budget period is ₹900000/-. The variable cost is evaluated to be ₹50/- unit produced. Each unit is sold at ₹250/-. The break even amount is
(A) ₹1,00,50,000/- (B) ₹11,25,000/-
(C) ₹9,50,000/- (D) ₹12,50,000/-

9. The fixed cost for a company for an year is ₹12,00,000/- The turn over for the year is to be ₹18,00,000/-. If the variable cost per unit of produced is ₹60/unit, and if the selling price is ₹300/-, the profit per year is
(A) ₹12,00,000/- (B) ₹2,40,000/-
(C) ₹2,60,000/- (D) ₹2,80,000/-

10. A man sells two identical machines at ₹2,40,000/-, one at a gain of 20% and the other at a loss of 18%. The profit or loss earned by the man in the dealing is
(A) ₹4000/- loss (B) ₹4,000/- gain
(C) ₹6,000/- loss (D) ₹6,000/- gain.

11. An analyst wants to obtain a cycle time estimate that is within ±5% of the true value. A preliminary run of 20 cycles took 40 min to complete and had a standard duration of 0.3 min. The coefficient of variation to be used for computing the sample size of the forthcoming study is
(A) 0.3 (B) 0.25
(C) 0.2 (D) 0.15.

12. A technique designed to establish the time for a qualified worker to carryout a specific job at defined level of performance is known as
(A) Method study
(B) Work study
(C) Work measurement
(D) Time and motion study.

13. In a 5 × 5 transportation matrix, the degeneracy would not arise if the number of the occupied cells are
(A) 25 (B) 10
(C) 24 (D) 9.

14. During a period, the actual demand was 118. But the predicted value was only 112. If the smoothing constant ∝ = 0.4. The forecast for the next period shall be
(A) 115 (B) 117
(C) 119 (D) 121.

15. The weekly demand of a product is x units. The ordering cost per order is ₹y. The inventory carrying cost is ₹z. per month/item. Then EOQ is given by
(A) $\sqrt{\frac{8.67x}{yz}}$ (B) $\sqrt{\frac{8.67z}{xy}}$
(C) $\sqrt{\frac{8.67xy}{z}}$ (D) $\sqrt{\frac{8.67y}{xz}}$.

16. The average consumption during unit lead time multiplied by the lead time for procurement of a product is known as
(A) Safety stock
(B) Buffer stock
(C) Emergency stock
(D) Reserve Stock.

17. In a single channel queue model, the average waiting time in the system is 60 min. But the mean weighting time in the queue to 30 min. Then the service rate will be
(A) 2/hr (B) 3/hr
(C) 4/hr (D) 1/hr.

18. When the ordering cost of a commodity is increased four times, the EOQ will be increased
(A) 3 times (B) 2 times
(C) 8 times (D) 4 times.

19. Two products A and B are produced by a firm. Both A + B require to be passed through three departments for its production. The departments are cutting, folding and finishing. The time requirement for each of A and B in various departments and the total hours available in each department are as indicated below.

Product A earns a profit of ₹ 80/- unit and B earns a profit of ₹ 60/unit.

The number of units of A and B to be produced for maximising the profit is

Departments	A	B	Total
Cutting	8	4	32
Folding	4	6	24
Finishing	7	5	35

(A) A = 9 Nos., B = 2 Nos.
(B) A = 7 Nos., B = 3 Nos.
(C) A = 4 Nos., B = 2 Nos.
(D) A = 3 Nos., B = 2 Nos.

20. A transportation problem is said not to degenerate when the number of occupied cells are (m = the number of rows, n = the number of columns)
(A) m + n (B) Greater than m + n
(C) m + n + 1 (D) m + n − 1.

21. In a system of queue, the arrival rate is 6 nos./hr and the service time is 8 min/person. The expected length of the queue is
(A) 3.2 (B) 2.8 (C) 2.2 (D) 1.8.

22. A company has a fixed cost of ₹ 8,00,000/-. But the variable cost per unit production is ₹ 250/-. The revenue obtainable by selling one unit of the product is ₹ 270/-. The break even quantity is
(A) 80,000 units (B) 40,000 units
(C) 20,000 units (D) 1,000 units.

23. In a network, the optimistic time is 6 months and the pessimistic time is 16 months. If the expected time is 9 months, the most likely time is
(A) 8 months (B) 9 months
(C) 10 months (D) 12 months .

Direction questions 24 and 25: The details of output and input for a production unit for a specified period of time is as stated below:

Total gross output = ₹ 5,000/-
Labour input = ₹ 800/-
Capital input = ₹ 1,400/-
Energy input = ₹ 200/-
Material input = ₹ 500/-
Miscellaneous expenses related to production = ₹ 300/-.

24. The factor productivity is
(A) 1.45 (B) 0.98
(C) 0.82 (D) 0.65.

25. Total productivity is
(A) 2.6 (B) 1.56
(C) 1.2 (D) 0.92.

Answer Keys

1. C	**2.** B	**3.** B	**4.** C	**5.** D	**6.** A	**7.** B	**8.** B	**9.** B	**10.** B
11. D	**12.** C	**13.** D	**14.** A	**15.** C	**16.** B	**17.** A	**18.** B	**19.** D	**20.** D
21. A	**22.** B	**23.** A	**24.** A	**25.** B					