Short Questions and Answers

1. Basics of Operations Research

1. **What is operations research?**
   There are many definitions of operations research. According to one such definition
   "Operations Research is the application of scientific methods to complex problems arising from operations involving large systems of men, machines, materials and money in industry, business, government and defence."

2. **What are the various types of models?**
   The various types of models are
   (*i*) Iconic or physical models
   (*ii*) Analogue or schematic models
   (*iii*) Symbolic or mathematical models.

3. **What is an analogue model?**
   Analogue model can represent dynamic situations. They are analogous to the characteristic of the system under study. They use one set of properties to represent some other set of properties of the system. After the model is solved, the solution is reinterpreted in terms of the original system.

4. **What is an iconic model?**
   Iconic models are the pictorial representations of real systems and have the appearance of the real structure. Examples of such models are city maps, houses, blueprints, etc.

5. **What is a symbolic model?**
   Symbolic model is one which employs a set of mathematical symbols to represent the decision variables of the system. These variables are related together by mathematical equations which describe the properties of the system.

6. **Name some characteristics of a good model.**
   (*i*) It should be simple and coherent.
   (*ii*) It should be open to parametric type of treatment.
   (*iii*) There should be less number of variables.
   (*iv*) Assumptions made in the model should be clearly mentioned and should be as small as possible.

7. **What are the main characteristics of operations research?**
   Some of the main characteristics of operations research are:
   (*i*) its system orientation.
   (*ii*) the use of inter-disciplinary forms.
   (*iii*) application of scientific method.
   (*iv*) uncovering of new problems.

8. **State any four applications of operations research.**
   (*i*) Assignment of jobs to applicants to maximize the total profits or minimize total costs.

(*ii*) Replacement techniques are used to replace the old machines with new ones.
(*iii*) Inventory control techniques are used in industries to purchase optimum quantity of raw materials.
(*iv*) Before executing a project, activities are sequenced and scheduled using the PERT chart.

9. **What are the methods used for solving operations research models?**
   (*i*) Analytic procedure
   (*ii*) Iterative procedure
   (*iii*) Monte-Carlo technique.

10. **Explain the principles of modelling?**
   (*i*) Models should be validated prior to implementation.
   (*ii*) Models are only aids in decision-making.
   (*iii*) Models should not be complicated. They should be as simple as possible.
   (*iv*) Models should be accurate as possible.

3. Graphical Method

11. **What do you mean by a general LPP?**

The general LPP is given by,

Max or Min $Z = C_1X_1 + C_2X_2 + ... + C_nX_n$ ...(1)

Subject to,

$$\left.\begin{aligned} &a_{11}X_1 + a_{12}X_2 + ... + a_{1n}X_n \ (\leq = \geq) b_1 \\ &a_{21}X_1 + a_{12}X_2 + ... + a_{2n}X_n \ (\leq = \geq) b_2 \\ &\vdots \\ &a_{m1}X_1 + a_{m2}X_2 + ... + a_{mn}X_n \ (\leq = \geq) b_m \end{aligned}\right\} \quad ...(2)$$

$$X_1, X_2 \ldots X_n \geq 0. \quad ...(3)$$

Equation (1) is called the objective function, (2) is the constraints obtained from the available resources and (3) is the non-negativity restriction.

12. **Give the matrix form of representing a general LPP.**

$$\text{Max or Min } Z = CX$$

$$\text{Subject to, } AX \begin{pmatrix} \leq \\ = \\ \geq \end{pmatrix}$$

$$X \geq 0$$

$$C = (C_1\, C_2 \ldots C_n) \times \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{pmatrix}, \; b = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{pmatrix},$$

$$A = \begin{pmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{12} & a_{22} & \ldots & b_{2n} \\ \vdots & \vdots & & \\ a_{m1} & a_{m2} & \ldots & a_{mn} \end{pmatrix}$$

13. **Define a feasible region.**
A region in which all the constraints are satisfied simultaneously is called a feasible region.

14. **Define a feasible solution.**
Any solution to a LPP which satisfies the non-negativity restrictions of the LPP is called its feasible solution.

15. **What is a redundant constraint?**
A constraint that does not form boundary of feasible region and has impact on the solution of the problem, remodel of which, does not alter the solution is called a redundant constraint.

16. **Define optimal solution.**
Any feasible solution which optimizes (minimizes or maximizes) the objective function is called its optimal solution.

17. **What is the difference between feasible solution and basic feasible solution?**
The solution of m basic variables when each of the $(n - m)$ non-basic variables is set to zero is called basic solution.

A basic solution in which all the basic variables are 0 is called a basic feasible solution.

18. **Define the following:**
(*i*) Basic solution
(*ii*) non-degenerate solution
(*iii*) degenerate solution.

(*i*) Basic solution
Given a system of m linear equations with n variables (m/n), any solution which is obtained by solving for m variables keeping the remaining $n - m$ variables as zero is called a basic solution.
Such m variables are called basic variables and $n - m$ variables are called non-basic variables.

(*ii*) Non-degenerate solution
A non-degenerate basic feasible solution is the basic feasible solution which has exactly m positive X_i $(i = 1, 2 \ldots\ldots\ldots m)$, i.e., none of the basic variables are zero.

(*iii*) Degenerate solution
A basic feasible solution is said to be degenerate if one or more basic variables are zero.

19. **Define unbounded solution.**
If the value of the objective function Z can be increased or decreased indefinitely. Such solutions are called unbounded solutions.

20. **What are the two forms of an LPP?**
The two forms of LPP are (*i*) Standard form and (*ii*) Canonical form.

21. **What do you mean by canonical form of a LPP?**
In canonical form, if the objective function is of maximization, then all the constraints other than non-negativity conditions are '≤' type. Similarly, if the objective function is of minimization, all the constraints are '≥' type.

22. **What do you mean by the standard form of LPP?**
In standard form, irrespective of the objective function namely maximize or minimize, all the constraints are expressed as equations, also right hand side constants are non-negative, *i.e.* all the variables are non-negative.

23. **State the characterstics of canonical form and write the canonical form of LPP in matrix form.**
Characteristics of canonical form
(*i*) The objective function is of maximization type.
(*ii*) All constraints are '≤' type.
(*iii*) All variables X_i are non-negative.

Matrix form

Max $Z = CX$
Subject to, $AX \le b$
$X \ge 0$

Or

Min $Z = CX$
Subject to, $AX \ge b$
$X \ge 0$

24. **State the characteristics of standard form and write the standard form of LPP in matrix form?**

Characteristics of standard form

(*i*) The objective function is of maximization type.
(*ii*) All constraints are expressed as equations.
(*iii*) RHS of each constraint is non-negative.
(*iv*) All variables are non-negative.

Matrix form

Max $Z = CX$

Subject to, $AX = b$

$X \geq 0$

25. **What are the limitations of LPP?**

(*i*) For larger problems having many limitations and constraints, the computational difficulties are enormous even when computers are used.
(*ii*) Many times it is not possible to express both the objective function and constraints in linear form.
(*iii*) The solution variables may have any values. Sometimes the solution variables are restricted to take only integer values.
(*iv*) This method does not take into account the effect of time.

26. **What are slack and surplus variables?**

The non-negative variable which is added to LHS of the constraint to convert the inequality $\leq$, into an equation is called slack variable.

$$\sum_{j=1}^{n} a_{ij} x_i + s_i = b_i \; (i = 1, 2 \ldots m)$$

where s_i are called *slack variables*.
The non-negative variable which is removed from the LHS of the constraint to convert the inequality into an equation is called a *surplus variable*.

27. **What are decision variables in the construction of operation research problems?**
While making mathematical modelling of operations research problems, the variables which are used and the value of which gives the solution are the decision variables.

28. **How many basic feasible solutions are there to a given system of 4 simultaneous equations in 5 unknowns?**

$$5C_4 = 5$$

29. **What is the test of optimality in the simplex method?**
Compute the net evaluation $Z_j - C_j$ $(j = 1, 2, \ldots\ldots n)$ by using the relations

$$Z_j - C_j = C_B (a_j - c_j)$$

If all $Z_j - C_j \geq 0$, then the current feasible solution is optimal, which is the test of optimality.

30. **What is key column and how is it selected?**
Key column is the column which gives the entering variable column and is selected by finding the most negative value of $Z_j - C_j$.

31. **What is key row and how is it selected?**

The leaving variable row is called the *key row* and is selected by finding the ratio

$$\text{Min}\left(\frac{x_{Bi}}{a_{ir}}, a_{ir} > 0\right)$$

i.e., the ratio between the solution column and the entering variable column by considering only the positive Dr.

32. **When does the simplex method indicate that the LPP has unbounded solution?**
The indication of unbounded solution of LPP can be obtained if all the variables in the key column are negative.

33. **What is meant by optimality?**
By performing optimality test we can find whether the current feasible solution can be improved or not, which is possible by finding the $Z_j - C_j$ row.

34. **How will you find whether a LPP has got an alternative optimal solution or not, from the optimal simplex table?**
In optimal simplex table, in $Z_j - C_j$ row, if zero occurs for non-basic variables, it indicates that the LPP has an alternate solution.

5. Artificial Variables Technique

35. **What are the methods used to solve an LPP involving artificial variables?**
(*i*) Big *M* method or penalty cost method
(*ii*) Two-phase simplex method

36. **Define artificial variable.**
Any non-negative variable which is introduced in the constraint in order to get the initial basic feasible solution is called artificial variable.

37. **When does an LPP possess a pseudo-optimal solution?**
An LPP possesses a pseudo-optimal solution, if at least one artificial variable is in the basis at positive level even though the optimality conditions are satisfied.

38. **What are the disadvantages of Big *M* method over two-phase method?**
Although Big *M* method can always be used to check the existence of a feasible solution, it may be computationally inconvenient because of the manipulation of the constant *M*. Also when the problem is to be solved on a digital computer, *M* must be assigned some numerical value which is greater than C_1, C_2.... in the objective function. But a computer has only a fixed number of digits. In two-phase method, these difficulties are overcome as it eliminates the constant *M* from calculations.

39. **What is degeneracy?**
The concept of obtaining a degenerate basic feasible solution in a LPP is known as degeneracy.

40. **Define the phenomenon of cycling.**
The phenomenon of repeating the same sequence of simplex iterations endlessly, without improving the value of the objective function is known as cycling.

41. **How can we resolve degeneracy in a LPP?**
(*i*) Divide each element of the rows by the positive coefficients of the key column in that row.
(*ii*) Compare the resulting ratios, column by column, first in the identity and then in the body from left to right.
(*iii*) The row which first contains the smallest ratio contains the leaving variable.

6. Duality in Linear Programming

42. **Define dual of LPP.**
For every LPP, there is a unique LPP associated with it involving the same data and closely related optimal solution. The original problem is then called *the primal problem* while the other is called its *dual problem*.

43. **What are the advantages of duality?**
(*i*) If primal contains a large number of constraints and a smaller number of variables, then the process of computations can be considerably reduced by converting it into the dual problem.
(*ii*) Since the optimal solution to the objective function is the same for both primal and dual, a dual solution can be used to check the accuracy of the primal solution.

8. Transportation Problem

59. **What do you understand by transportation problem (T.P.)?**
T.P. is a special class of Linear Programming Problem in which we transport a commodity (single product) from the source to a destination in such a way that the total transportation cost is minimum.

60. **Define feasible, basic feasible, non-degenerate solution of a T.P.**
Refer to the definitions in the chapter.

61. **Give reasons as to why the LPP solution techniques are not made use of while solving a T.P.**
As there are $m + n - 1$ equations in a T.P. with m origins and n destinations, by adding an artificial variable to each equation, a large number of variables are involved.

(*i*) If the problem has m sources and n destinations and $m + n - 1$ equations can be formed. Hence, computation may exceed the capacity of the computer. So LPP technique is not made use of while solving a T.P.

(*ii*) The coefficient x_{ij} in the constraints are all in unity. For such a technique, transportation technique is easier than simplex method.

(*iii*) T.P. is minimization of objective function, whereas, simplex method is suitable for maximization problem.

62. **List any three approaches used with T.P. for determining the starting solution.**
(*i*) North-west corner rule
(*ii*) Least cost method (Matrix Minima)
(*iii*) Vogel's approximation method.

63. **Define the optimal solution to a T.P.**
The basic feasible solution to a T.P. is said to be optimal, if it minimizes the total transportation cost.

64. **State the necessary and sufficient condition for the existence of a feasible solution to a T.P.**
The necessary and sufficient condition for the existence of a feasible solution is a solution that satisfies all the conditions of supply and demand.

65. **What is the purpose of MODI method?**
The purpose of MODI method is to get the optimal solution of a T.P.

66. **When does a T.P. have a unique solution?**
A T.P. has a unique solution, if the net evaluation given by $C^*_{ij} = C_{ij} - (u_i + v_j)$ of all the empty cells are positive, i.e., of all $\Delta_{ij} > 0$.

67. **What do you mean by degeneracy in a T.P.?**
If the number of occupied cells in a $m \times n$ T.P. is less than $m + n - 1$, then it is called a degeneracy in a T.P.

68. **Explain how degeneracy in a T.P. may be resolved?**
This degeneracy in a T.P. can be resolved by adding one (more) empty cell having the least cost and is of independent position with a non-negative allocation ($\varepsilon > 0$).

69. **What do you mean by an unbalanced T.P.?**
Any T.P. is said to be unbalanced if

$$\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} b_j$$

i.e., if the total supply is not equal to the total demand.

70. **How do you convert an unbalanced T.P. into a balanced one?**
The unbalanced T.P. can be converted into a balanced one by adding a dummy row (source) with cost zero and the excess demand is entered as a rim requirement, if total supply < total demand. On the other, hand if the total supply > total demand, we introduce a dummy column (destination) with cost 0 and the excess supply is entered as a rim requirement for the dummy destination.

71. List the merits and limitations of using North-west corner rule.
Merits This method is easy to follow because we need not consider the transportation cost.
Limitations The solution obtained may not be the best solution, as the allocations have been made without considering the cost of transportation. While performing optimality test, it may need more iterations to get the optimal solution.

72. Vogel's approximation method results in the most economical initial basic feasible solution. Why?
Yes, it is true. In this method we take into account not only the least cost c_{ij} but also the costs that just exceed c_{ij}. This method considerably reduces the number of iteration required to arrive at the optimal solution. Also it gives near optimal solution that may, at times, be the optimal solution.

73. How will you identify that a T.P. has got an alternate optimal solution?
While performing optimality test, if some of Δ_{ij} value, where $\Delta_{ij} = C_{ij} - (u_i + v_j)$ for empty (non-basic) cell is zero, then it is the indication of an alternate solution.

74. The number of non-basic variables in the balanced T.P. with m rows and n columns is $mn - (m + n - 1)$.

75. The number of non-basic variables in the balanced T.P. with 4 rows and 5 columns is 12.

76. In the north-west corner rule, if the demand in the column is satisfied, one must move to the right cell in the next column.

77. For any T.P., the coefficients of all x_{ij} in the constraints are unity.

78. An optimum solution results when net change value of all unoccupied cells are non-negative.

79. A solution that satisfies all the conditions of supply and demand but it may or may not be optimal is called an initial feasible solution.

80. Degeneracy in a $m \times n$ T.P. occurs when the number of occupied cell is less than $m + n - 1$.

81. When do you say that the occupied cell is in independent position?
An occupied cell is in independent position, when no closed path can be drawn from the allocations.

82. The transportation model is restricted to dealing with a single commodity only. Is it true or false. (False.)

83. If a constant value is added to every cost element c_{ij} in the transportation table, the optimal values of the variable x_{ij} will change. Is it true or false. (False.)

9. Transhipment and Assignment Problems

84. **What is an assignment problem? Give two applications.**
The problem of assigning the number of jobs to equal number of facilities (machines or persons or destinations) at a minimum cost or maximum profit is called an assignment problem.
Applications:

(*a*) If n jobs have to be assigned to n workers or machines with unit cost or unit time of performing the job, we can use assignment model to get minimum cost.

(*b*) Travelling salesmen problem, i.e., a salesman has to visit a number of cities, not visiting the same city twice and return to the starting place.

85. **What do you mean by an unbalanced assignment problem?**
If the number of rows is not equal to the number of columns in the cost matrix of the assignment problem or if the cost matrix of the given assignment problem is not a square matrix, then the given assignment problem is said to be unbalanced.

86. **Why can the transportation technique or the simplex method not be used to solve the assignment problem?**
The transportation technique or simplex method cannot be used to solve the assignment problem because of degeneracy.

87. **State the difference between the T.P. and the A.P.**
The major differences between T.P. and A.P. are,
(*i*) The cost matrix in T.P. is not necessarily a square matrix, whereas in A.P., it is a square matrix.
(*ii*) Supply and demand at any source and at any destination may be positive quantity a_i, b_j in T.P. whereas in A.P. it will be 1, i.e., $a_i = b_j = 1$.
(*iii*) The allocations X_{ij} in the case of T.P. can take any positive values satisfying the rim requirements, whereas in A.P., X_{ij} will take only two possible values 1 or 0.

88. **How is the presence of an alternate optimal solution established?**
If the final cost matrix contains more than a required number of zeros at independent positions, then it indicates the presence of an alternate optimal solution.

89. **What is the objective of the travelling salesman problem?**
The objective of the travelling salesman problem is that the salesman has to visit various cities, not visiting the same place twice and return to the starting place by spending minimum transportation cost.

90. **How do you convert the maximization assignment problem into a minimization one?**
The maximization A.P. can be converted into minimization assignment problem by subtracting all the elements in the given profit matrix from the highest element in that matrix.

91. **If each entry is increased by 3 in a 4 × 4 assignment problem, what is the effect on the optimal value?**
The effect in the optimal value when each entry is increased by 3 is given by
New optimal value = Original optimal value + 3 × 4, where 4 is the order of matrix.

92. **Give the linear programming form of the A.P.**
The A.P. can be expressed as

$$\text{Minimize } Z = \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}X_{ij}$$

where C_{ij} is the cost of assigning i^{th} machine to the j^{th} job, subject to the constraints

$$X_{ij} = \begin{cases} 1 \text{ if } i\text{th machine is assigned to the } j\text{th job} \\ 0 \text{ if not.} \end{cases}$$

93. **Why is A.P. a completely degenerate form of a T.P.?**
Since the units available at each source and the units demanded at each destination are equal, we get exactly one occupied cell in each row and each column. Hence, we get only n occupied cells in the place in the required $n + n - 1 = 2n - 1$ occupied cells. Hence, an A.P. is a completely degenerate form of a T.P.

94. **The optimum assignment schedule remains unnoticed, if we add or subtract a constant from all the elements of a row or column of the assignment cost matrix. Is this statement true?**
The above statement is true, optimal schedule will not be altered. But the optimal value will be changed (refer to Q. No. 91).

95. **What is the name of the method used in getting the optimum assignment?**
Hungarian method.

96. **When is an A.P. said to be unbalanced? How do you make it a balanced one?**
If the cost matrix or profit matrix is not a square matrix, then the problem is said to be unbalanced. To make it balanced, we add a row or column accordingly with all the entries zero.

97. An A.P. is a completely degenerate form of a T.P.

98. An A.P. represents a T.P. with all demands and supplies equal to 1.

99. The transportation technique or simplex method cannot be used to solve the A.P. because of Degeneracy.

100. The A.P. can be stated in the form of a $n \times n$ matrix (C_{ij}) called Cost matrix or effective matrix.

101. **How do you solve an A.P., if the profit is to be maximised?**
The given profit matrix can be converted into a loss matrix or minimization type by subtracting all the elements from the highest element of the given matrix. For this minimization problem, apply steps of the Hungarian method to get an optimal assignment.

15. Network Scheduling by PERT/CPM

128. **What do you mean by a project?**
A project is defined as a combination of inter-related activities all of which must be executed in a certain order for its completion.

129. **What are the two basic planning and control techniques in a network analysis?**
(*i*) Programme Evaluation Review Technique (PERT)
(*ii*) Critical Path Method.

130. **What are the three main phases of a project?**
The three phases of a project are planning, scheduling and control.

131. **What is a network?**
It is the graphic representation of logically and sequentially connected arrows and nodes representing activities and events of a project.

132. **What do you mean by an activity of a project?**
An activity represents some action and as such is a time consuming effort necessary to complete a particular part of the overall project.

133. **What is a dummy activity and when is it needed?**
Certain activities which neither consume time nor resources, but are used simply to represent a connection between events are known as dummies. When two activities have the same head and tail events, they cannot be represented in a network diagram without using dummy activity.

134. **What are the three common errors in the construction of network?**
The three common errors are (*i*) Formation of loops (*ii*) Dangling (*iii*) Redundancy.

135. **What is dangling in a network?**
To disconnect an activity before the completion of all activities in a network diagram is known as dangling.

136. **How is dangling avoided in the network?**
The dangling can be avoided by adding a dummy activity. This can be connected to the end event.

137. **Distinguish between float and slack.**
The basic difference between slack and float is that slack is used for the difference between the latest and earliest event time whereas float is the same difference used for the activity.

138. **What are the three types of floats?**
The three types of floats are (*i*) Total float (*ii*) Free float (*iii*) Independent float.

139. **What is the name of the activity whose total float is zero?**
Critical activity.

140. **What is the name of the rule used for numbering the events?**
Fulkerson rule.

141. **Define total float.**
The amount of time by which the completion of an activity could be delayed beyond the earliest expected completion time without affecting the overall project duration time is called the total float.

142. **Define critical activity.**
An activity is said to be critical if a delay in its start will cause a further delay in the completion of the entire project.

143. **What is the critical path?**
The sequence of critical activities in a network is called the critical path.

144. **Can the total float be negative?**
No.

145. Earliest finish of an activity can be calculated by a formula $Es_j - \text{Max}_i = (E_{si} + t_{ij})$ where Es_i is the earliest start time and t_{ij} is the normal time.

146. **Can a dummy activity appear on the critical path of a project network?**

Yes.

147. **If the total float of an activity 3 – 4 is 18, the latest and the earliest occurrence of the events 3 and 4 are 15, 12 and 22, 10 respectively. What is free float?**

$FF = TF$ – Head event slack = $18 - (22 - 10) = 6$.

148. **What is the independent float of the activity 3 – 4 in question 147?**

$IF = FF$ – Tail event slack = $6 - (15 - 12) = 6 - 3 = 3$.

149. **Distinguish between PERT and CPM.**

PERT	*CPM*
(*i*) Event oriented.	(*i*) Activity oriented.
(*ii*) Probabilistic.	(*ii*) Deterministic.
(*iii*) Three time estimates namely optimistic, pessimistic, most likely are given.	(*iii*) Time is fixed.
(*iv*) Resourcess such as labour, equipments, materials are limited.	(*iv*) No limitation of resources.

150. **Define the expected variance of a project length.**

The expected variance of a project length, also called the variance of the critical path, is the sum of the variances of all the critical activities.

151. **Express the expected duration of an activity of a project in terms of t_o, t_m and t_p.**

The expected duration of an activity in terms of the three time estimates is given by

$$t_e = \frac{t_e + 4t_m + t_p}{6}$$

152. **What is the formula for finding the variance of an activity in terms of optimistic and pessimistic time estimates?**

The formula for variance σ^2 in terms of t_o and t_p is given by

$$\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$$

153. The name of the probability distribution used in PERT which estimates the expected duration and the expected variance of the activity is β-distribution.

154. Write down at least two main assumptions in PERT network calculation.

(*i*) The activity durations are independent, i.e., the time required to complete an activity will have no bearing on the completion times of any other activity of the project.

(*ii*) The activity durations follow β-distribution.

155. **For a standard normal variable Z, $P(0 \le z \le 1) = 0.4313$, if the expected duration of a project is 40 days and the standard deviation of the critical path is 5 days, what is the probability of completing the project in 35 days?**

The probability of completing the project within 35 days is given by $P(Z \le D)$

18. Queueing Theory

235. **Define a queue.**
The flow of customers from finite/infinite population towards service facility is called a queue (waiting line).

236. **Define a customer.**
The arriving unit that requires some service to be performed is called a customer.

237. **What are the basic characteristics of a queueing system?**
The basic characteristics of a queueing system are
(*i*) the input (arrival pattern)
(*ii*) the service mechanism (service pattern)
(*iii*) the queue discipline
(*iv*) customer behaviour.

238. **Define the following:**
(*i*) **Balking** A condition in which a customer may leave the queue because the queue is too long and he has no time to wait or there is insufficient waiting space.
(*ii*) **Reneging** This occurs when a waiting customer leaves the queue due to impatience.
(*iii*) **Jockeying** Customers may jockey from one waiting line to another.

239. **Define transient and steady state.**
A system is said to be in a transient state when its operating characteristics are dependent on time. When the operating characteristics of a system are independent of time, it is called a steady state.

240. **Define traffic intensity or utilization factor.**
An important measure of a simple queue is its traffic intensity given by

$$\rho = \frac{\text{Mean arrival rate}}{\text{Mean service rate}} = \frac{\lambda}{\mu}$$

241. **Explain Kendall's notation.**
Kendall's notation is used for representing queueing models. Generally queueing model may be completely specified in the following symbol form (*a/b/c*); (*die*)
a = inter-arrival time (arrival pattern)
b = service pattern
c = number of channels
d = capacity of the system
e = queue discipline

242. **Give the formula for probability of n units in the system under single server, FCFS discipline.**

$$P_n = \left(\frac{\lambda}{\mu}\right)^n P_0, P_0 = 1\left[\frac{\lambda}{\mu}\right]$$

where, λ and μ are mean arrival and mean service rate respectively.

243. **What is the distribution for service time?**
The distribution for service time is exponential with mean $\frac{1}{\mu}$.

244. The inter-arrival time under queue follows a Poisson distribution.

245. **Write Little's formula.**
$L_s = \lambda w_s$
$L_q = \lambda w_q$
$L_q = L_s - \lambda/\mu.$

246. Constant service time is a special case of Erlang service time.

247. The time interval between consecutive arrivals generally follows exponential distribution.

248. **What do you understand by explosive state?**

If $\frac{\lambda}{\mu} > 1$, then the state is referred as explosive state.

249. M/M/1 model is also known as Birth-Death model.

19. Game Theory

250. **Define a game.**

The competitive situation will be called a game, if it has the following properties:

(*i*) There is a finite number of participants called players.

(*ii*) Each player has a finite number of strategies available to him.

(*iii*) Every game results in an outcome.

251. **Define strategy.**

The strategy of a player is the decision rule he uses for making the choice from his list of courses of action.

252. **What are the classification of strategy?**

The classifications of strategy are:

(*a*) Pure strategy and (*b*) Mixed strategy.

253. **When do players apply mixed strategies?**

Players apply mixed strategy when there is no saddle point.

254. **Define a saddle point.**

A saddle point is the position in the pay-off matrix, where the maximum of row minima coincides with the minimum of column maxima.

255. **Define two-person zero sum game.**

A game with two players, where a gain of one player equals the loss of the other is known as a two-person zero sum game.

256. **Distinguish between Pure and Mixed strategies.**

(*i*) A strategy is called pure, if one knows in advance of the play that it is certain to be adopted irrespective of the strategy the other may choose. The optimal strategy mixture for each player may be determined by assigning to each strategy its probability of being chosen. These strategies are called mixed strategy.

(*ii*) A pure strategy is a special case of mixed strategy. A player may be able to choose only n pure strategies, whereas he had infinite number of mixed strategies.

257. Games without saddle point require players to play Mixed strategies.

258. Saddle point is the point of intersection of pure strategies.

259. **A pure strategy game is one in which each player has only one optimal strategy—True or False.**

True.

260. **Define pay-off.**

The gains resulting from a game is called pay-off, and when it is presented in the form of a table, it is called pay-off matrix.

261. **What type of games are solved graphically?**

The games in which the pay-off matrix is of the form $m \times 2$ or $2 \times n$ are solved graphically.

262. **Define value of the game.**

The value of the game is defined as the expected gain to a player.

263. **What is meant by minimax, maximin?**

Minimax is maximum of row minima, and Maximin is minimum of column maxima.

264. **When do you say a game is stable?**

A game is stable when there is a saddle point.