GATE

2018

INDUSTRIAL ENGINEERING

MECHANICAL ENGINEERING

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GATE-2018: Industrial Engineering| Detailed theory with GATE & ESE previous year papers and detailed solutions.

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SECTION- A
INDUSTRIAL ENGINEERING

CHAPTER - 1
LINEAR PROGRAMMING

1.1 LPP (LINEAR PROGRAMMING PROBLEM)

Linear programming is a technique which allocates scare available resources under conditions of certainty in an optimum manner, (i.e. maximum or minimum) to achieve the company objectives which may be maximum overall profit or minimum overall cost.

Linear programming deals with the optimization (maximization or minimization) of linear functions subjects to linear constraints. It is a mathematical method used to determining best optimal solution from a number of possible solutions. It is used mainly for optimization of resources within limited resources.

1.1.1 Example of L.P.P

Solution by graphical method

Maximize $(z) = 3x_1 + 4x_2$ …(i)

Subject to $4x_1 + 2x_2 \geq 80$ …(ii)

$2x_1 + 5x_2 \leq 180$ …(iii)

$x_1, x_2 \geq 0$ …(iv)

1.The variable that enters into the problem are called decision variables, e.g., x_1, x_2

2.The expression showing the relationship between the manufacture's goal and the decision variables is called the objective function, e.g. $= 3x_1 + 4x_2$ (maximize)

3.The inequalities (ii); (iii); (iv) are called constraints being all linear, it is a linear programming problem (L.P.P).

1.1.2 Graphical Method

1.1.2.1 *Working Procedure*

Step-I

Formulate the given problem as a linear programming problem.

Step-II

Plot the given constraints as equalities on x_1. x_2 co-ordinate plane and determine the convex region formed by them.

[A region or a set of points is said to be convex if the line joining any two of its points lies completely in the region (or the set)]

Step-III

Determine the vertices of the convex region and find the value of the objective function and find the value of the objective function at each vertex. The vertex which gives the optimal value of the objective function gives the desired optimal solution the problem.

1.1.3 Otherwise

Draw a dotted line through the origin representing the objective function with $z = 0$. As z is increased from zero, this line moves to the right remaining parallel to itself. We go on sliding this line (parallel to itself), till it is farthest away from the origin and passes through only one vertex on the convex region. This is the vertex where the maximum value of z is attained.

When it is required to minimize z_n value z is increased till the dotted line passes through the nearest vertex of the convex region.

Example. Maximize $z = 3x_1 + 4x_2$

Subject to $4x_1 + 2x_2 \geq 80$

$2x_1 + 5x_2 \leq 180$

GATE QUESTIONS

1. Maximize $Z = 5x_1 + 3x_2$
Subject to $x_1 + 2x_2 \le 10$, $x_1 - x_2 \le 8$, $x_1, x_2 \ge 0$
In the starting simplex tableau, x_1 and x_2 are non - basic variables and the value of Z is zero. The value of Z in the next simplex tableau is ____
[GATE - 2017]

2. Two models, P and Q, of product earn profits of Rs. 100 and Rs. 80 per piece, respectively. Production time for P and Q are 5 hours and 3 hours, respectively, while the total production time available is 150 hours. For a total batch size of 40, to maximize profit, the number of units of P to be produced is ____.
[GATE - 2017]

3. Maximize $Z = 15X_1 + 20X_2$
Subject to
$12X_1+4X_2 \ge 36$
$12X_1-6X_2 \le 24$
$X_1, X_2 \ge 0$
The above linear programming in problem has
[GATE - 2016]
(a) Infeasible solution
(b) Unbounded solution
(c) Alternative optimum solutions
(d) Degenerate solution

4. For linear programming problem
Maximize $Z = 3X_1 + 2X_2$
Subject to
$-2X_1+3X_2 \le 9$
$X_1 - 5X_2 \ge -20$
$X_1, X_2 \ge 0$
The above problem has
[GATE - 2015]
(a) Unbounded problem
(b) Infeasible solution
(c) Alternative optimum solution
(d) Degenerate solution

5. Consider an objective function $Z(x_1, x_2) = 3x_1 + 9x_2$ and the constraints
$x_1 + x_2 \le 8$
$x_1 + 2x_2 \le 4$
$x_1 \ge 0, x_2 \ge 0$
The maximum value of the objective function is _________.
[GATE - 2014]

6. A linear programming problem is shown below:
Maximize
$3x + 7y$
Subject to
$3x + 7y \le 10$
$4x + 6y \le 7$
$X, y \ge 0$
It has
[GATE - 2013]
(a) An unbounded objective function
(b) Exactly one optimal solution
(c) Exactly two optimal solution
(d) Infinitely many optimal solution

Common Data Q.7 & Q.8
One unit of product P_1 requires 3 kg of resource R_1 and 1 kg resource R_2. One unit of product P_2 requires 2 kg of resource R_1 and 2 kg of resource R_2. The profits per unit by selling product P_1 and P_2 and Rs. 2000 and Rs. 3000 respectively. The manufacturer has 90 kg or resource R_1 and 100 kg of resource R_2.

7. The manufacturer can make a maximum profit of Rs.
[GATE - 2011]
(a) 60000 (b) 135000
(c) 150000 (d) 200000

8. The unit worth of resource R_2, i.e. dual price of resource R_2 in Rs. Per kg is
[GATE - 2011]
(a) 0 (b) 1350
(c) 1500 (d) 2000

9. Simplex method of solving linear programming problem uses

ESE OBJ QUESTIONS

1. Objective function
$Z = 5X_1 + 4X_2$(Maximize)
Subject to
$0 \le X_1 \le 12$
$0 \le X_2 \le 9$
$3X_1 + 6X_2 \le 66$
$X_1 , X_2 \ge 0$
What is the optimum value?
[ESE - 2015]
(a) 6, 9 (b) 12, 5
(c) 4, 10 (d) 0, 9

2. Maximum $Z = 2X_1 + 3X_2$
Subject to
$2X_1 + X_2 \le 6$
$X_1 - X_2 \ge 3$
$X_1, X_2 \ge 0$
The solution to the above LPP is
[ESE - 2015]
(a) Optimal (b) Infeasible
(c) Unbounded (d) Degenerate

3. A transportation problem consists of 3 sources and 5 destinations with appropriate rim conditions , The number of possible is
[ESE - 2015]
(a) 15 (b) 225
(c) 6435 (d) 150

4. Assuming X and Y are the two control variables , the following are the constraints laid out for maximizing the profit :
Maximize profit (P) = 8X +5Y
Subject to
Constraint -1:$2X + Y \le 1000$
Constraint -2: $3X + 4Y \le 2400$
Constraint -3: $X + Y \le 800$
Constraint -4: $X - Y \le 350$
Constraint -5: $X \ge 0$
Constraint -6: $Y \ge 0$
Which of the above constraints is a redundant one and does not have any effect on the solution?
[ESE - 2015]
(a) Constrain -1
(b) Constraint -3
(c) Constraint - 4
(d) Constraint -5 and Constraint - 6

5. In simplex method , the variables which have not been assigned the value zero during the iteration , are called
[ESE - 2015]
(a) Basic variables
(b) Actual variables
(c) Artificial variables
(d) None of the above

6. An unbound solution of linear programming problem is reflected in the simplex method, when
[ESE - 2011]
(a)All the ratio of 'right hand sides' to coefficients in key columns becomes negative
(b)All the ratios of right hand sides to coefficients in key columns become zero
(c)All right hand side become negative
(d)All right hand sides become zero

7. The leaning basic variables in simplex method is the basic variable that
[ESE - 2010]
(a)Has the lowest value
(b)Has the largest coefficient in the key row
(c)Has the smallest coefficient in the key row
(d)Goes to zero first as the entering basic variable in increased

8. Consider the following statements :
1. Resources limitations must be know
2. Relationship of variables must be known
Which of these statements must be satisfied to deal with the graphical techniques of linear programming effectively ?
[ESE - 2010]
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 or 2

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CHAPTER - 2
INVENTORY

2.1 INTRODUCTION
It is the stock of item or resources used in organization. It may be defined as the stock on hand at a given time and it may be held for purpose of letter use or sale. It is usable but idle resources having an economic value and it may include raw material, work in process inventory, semi finished inventory and finished goods.
A fundamental objective of a good system of operation control of Inventories is to be able to place an order at the right time,
From the right source
To acquire the right quantity
At right price
And right quality
"Inventory is the life blood of a production system."

2.2 CATEGORIES
1. Production inventories: go to final product
2. MRO (Maintenance, Repair and operating supplies) e.g. spare parts, oils grease.
3. In-process inventories (semi-finish products at various production stages)
4. Finished goods inventories
5. Miscellaneous inventory

2.3 ANOTHER WAY OF CLASSIFYING INDUSTRIAL INVENTORIES ARE
1. Transition inventory
2. Speculative inventory
3. Precautionary inventory

2.4 SELECTIVE INVENTORY CONTROL
2.4.1 Different type of Inventory Analysis
1. ABC analysis (class A, class B, class C)
2. VED Analysis (vital, Essential, Desirable)
3. SDE Analysis (Scarce, Difficult, Easily Available)
4. HML Analysis (High, Medium, Low Cost)
5. FSN Analysis (Fast, Slow, Non-moving items)

2.4.2 ABC Analysis
The common and important of the selective inventory control of ABC analysis. ABC Analysis is done for items on stock and the basis of analysis is the annual consumption in terms of money value.
Control of A – item: 10 % of the item accounts 70% costs
Control of B – item: 20% of the item accounts 20% costs
Control of C – item: 70% of the items accounts 10% costs

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ASSIGNMENT

1. Inventory management consists of
(a) Effective running of stores
(b) State of merchandise methods of storing and maintenance etc.
(c) Stock control system
(d) all of the above

2. Inventory can be in the form of
(a)Raw materials
(b)In process goods
(c)Brought out part, semi finished goods and subassemblies
(d)All of the above

3. Two groups of costs in inventory control are
(a) Carrying costs and ordering costs
(b) Relevant cost and ordering costs
(c) Carrying costs an total costs
(d) Relevant costs and total costs

4. In basic economic order quantity model for the optimal order quantity
(a) Holding cost is more than ordering cost
(b) Holding cost is less than ordering cost
(c) Holding cost is equal to ordering cost
(d) Holding cost is two times the ordering cost

5. In inventory planning, extra inventory is unnecessary carried to the end of the planning period when using one of the following size decision policies.
(a) Lot for lot production
(b) Economic order quantity (EOQ) lot size
(c) Period order quantity (POQ) lot size
(d) Part period total cost balancing

6. The formula for economic order quantity does not contain
(a) Order cost
(b) Carrying cost
(c) Cost of the item
(d) Annual demand

7. For a given annual consumption, the minimum total inventory cost is proportional to square root of the product of
(a) Ordering cost per order
(b) Carrying cost per until per year
(c) Both (a) and (b) above
(d) None of the above

8. When order quantity increases the ordering costs will
(a) Increase
(b) Decrease
(c) Remains same
(d) None of the above

9. One of the important reasons for carrying inventory is to
(a) Improve customer service
(b) Get quantity discounts
(c) Maintain operational capability
(d) All of the above

10. A shop owner with an annual constant demand of `R` units has ordering costs of Rs. ‘C_O’ per order and carrying costs Rs. ‘C_O’ per unit per year. The economic order quantity for a purchasing model having no shortage may be determined from
(a) $\sqrt{\dfrac{24R}{C_C R_O}}$ (b) $\sqrt{\dfrac{24RC_O}{C_C}}$
(c) $\sqrt{\dfrac{2RC_O}{C_C}}$ (d) $\sqrt{\dfrac{2RC_C}{C_O}}$

11. Which of the following is not a part of inventory Carrying Cost?
(a) Cost of storage Cost
(b) Cost of obsolescence
(c) Cost of insurance
(d) Cost of inwards goods inspection

12. Setup costs do not include
(a) Labour cost of setting up machines
(b) Ordering cost of raw material

GATE QUESTIONS

1. The annual demand for an item is 10, 000 units .The unit cost is Rs. 100 and inventory carrying charges are 14.4% of the unit cost per annum. The cost of one procurement is Rs 2000.The time between two consecutive orders to meet the above demand is _______month(s).

[GATE - 2016]

2. The annual requirement of rivets at a ship manufacturing company is 2000kg .The rivets are supplied in units of 1kg costing Rs 25 each. If the costs Rs.100 to place an order and the annual cost of carrying one unit is 9% of its purchase cost , the cycle length of the order (in days) will be

[GATE - 2015]

3. A food processing company uses 25, 000kg of corn flour every year .The quantity –discount price of corn flour is provided in the table below :

Quantity (kg)	Unit price (Rs/kg)
1-749	70
750-1499	65
1500 and above	60

The order processing charges are Rs 500 order. The handling plus carry over charge on an annual basis is 20% of the purchase price of the corn flour per kg .The optimal order quantity (in kg) is ________

[GATE - 2015]

4. A manufacturer can produce 12000 bearings per day. The manufacturer received an order of 8000 bearings per day from a customer. The cost of holding a bearing in stock is Rs. 0.20 Per month.. Setup cost per production run is Rs. 500. Assuming 300 working days in a year, the frequency of production run should be

[GATE - 2014]

(a) 4.5 days
(b) 4.5 months
(c) 6.8 days
(d) 6.8 months

5. Consider the following data with reference to elementary deterministic economic order quantity model

Annual demand of an item	100000
Unit price of the item (in Rs.)	10
Inventory carrying cost per unit per year (in Rs.)	1.5
Unit order cost (in Rs.)	30

The total number of economic orders per year to meet the annual demand is _______

[GATE - 2014]

6. A component can be produced by any of the four processes I, II, III and IV. The fixed cost and the variable cost for each of the processes are listed below. The most economical process for producing a batch of 100 pieces is

Process	Fixed Cost (in Rs.)	Variable cost Per piece (in Rs.)
I	20	3
II	50	1
III	40	2
IV	10	4

[GATE - 2014]

(a) I
(b) II
(c) III
(d) IV

7. Annual demand for window frames is 10000. Each frame costs Rs. 200 and ordering cost is Rs. 300 per order. Inventory holding cost is Rs. 40 per frame per year. The supplier is willing to offer 2% discount if the order quantity is 1000 or more, and 4% if order quantity is 2000 or more. If the total cost is to be minimized, the retailer should

[GATE - 2010]

(a) Order 200 frames every time
(b) Accept 2% discount
(c) Accept 4% discount
(d) Order Economic Order Quantity

8. A company uses 2555 units for an item annually. Delivery lead time is 8 days. The reorder point (in number of units) to achieve

CHAPTER - 3
TRANSPORTATION

3.1 TRANSPORTATION PROBLEM
These are used for meeting the supply and demand requirement under given conditions.
This is a special class of L.P.P. in which the objective is to transport a single commodity from various origins to different destinations at a minimum cost. The problem can be solved by simplex method. But the number of variables being large, there will be too many calculations.

3.2 FORMULATION OF TRANSPORTATION PROBLEM
There are m plant locations (origins) and n distribution centers (destinations). The production capacity of the i^{th} plant is a_i and the number of units required at the j^{th} destination bj. The Transportation cost of one unit from the i^{th} plant to the j^{th} destination c_{ij}. Our objective is to determine the number of units to be transported from the i^{th} of plant to j^{th} destination so that the total transportation cost is minimum.
Let x_{ij} be the number of units shipped from i^{th} plant to j^{th} destination, then the general transportation problem is:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}\, x_{ij}$$

Subjected to
$x_{i1} + x_{i2} + \text{-------}+ x_{in} = a_i$ (for i^{th} origin i = 1, 2, ……..,m)
$x_{ij} + x_{2j} + \text{-------}+ x_{mj} = n_j$ (for j^{th} origin i = 1, 2, ……..,n)
$x_{ij} \geq 0$

The two sets of constraints will be consistent if $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$, which is the conditions for a transportation problem to have a feasible solution? Problems satisfying this condition are called balanced transportation problem.

3.3 DEGENERATE OR NON-DEGENERATE
A feasible solution to a transportation problem is said to be basic feasible solution of it contains at the most (m + n – 1) strictly positive allocations, otherwise the solution will 'degenerate'. If the total number of positive (non-zero) allocations is exactly (m + n – 1), then the basic feasible solution is said to be non-degenerate, if '(m + n – 1)' $\rightarrow$ no. of allocated cell. Then put an $\varepsilon \rightarrow 0$ at a location so that all ui, vj can be solved and after optimality check put $\varepsilon = 0$.
Optimal solution: The feasible solution which minimizes the transportation cost is called an optimal solution.

3.4 WORKING PROCEDURE FOR TRANSPORTATION PROBLEMS
Step-I
Construct transportation table: if the supply and demand are equal, the problem is balance. If supply and demand is not same then add dummy cell to balance it.
Step-II
Find the initial basic feasible solution. For this use **Vogel's approximation Method (VAM)**. The VAM takes into account not only the least cost c_{ij} but also the costs that just exceed the least cost c_{ij} and therefore yield a better initial solution than obtained other methods. As such we shall confine ourselves to VAM only which consists of the following steps:

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ASSIGNMENT

1. The occurrence of degeneracy while solving a transportation problem means that
(a) Total supply equals total demand
(b) The solution so obtained is not feasible
(c) The few allocations become negative
(d) None of the above

2. Penalty cost method is
(a) Least cost method
(b) North West corner method
(c) Vogel's approximation method
(d) None

3. One disadvantage of using North-West corner Rule of find initial solution to the transport-tation problem is that
(a)It is complicated to use
(b)It does not take into account cost of transportation
(c)It leads to a degenerate initial solution
(d)All of the above

4. The degeneracy in the transportation problem indicates that
(a) Dummy allocation(s) needs to be added
(b) The problem has no feasible solution
(c) The multiple optimal solution exist
(d) (a) and (b) but not (c)

5. The solution in a transportation model (of dimension m x n) is said to be degenerate if it has
(a) Exactly (m + n – 1) allocations
(b) Fewer than (m + n – 1)
(c) More than (m + n -1) allocations
(d) (m x n) allocations

6. In a transportation problem, the materials are transported from 3 plants to 5 warehouses. The basic feasible solution must contain exactly, which one of the following allocated cells?
(a) 3 (b) 5
(c) 7 (d) 8

7. Which one of the following is not the solution method of transportation problems?
(a) Hungarian method
(b) Northwest corner method
(c) Least cost method
(d) Vogel's approximation method

8. The supply at three sources is 50, 40 and 6 units respectively while the demand at the four destinations is 20, 30, 10 and 50 units. In solving this transportation problem.
(a)A dummy sources of capacity 40 units is needed
(b)A dummy destination of capacity 40 units is needed
(c)No solution exists as the problem is infeasible
(d)None solution exists as the problem is degenerate.

9. Consider the following statements:
(a) For the application of optimality test in case of transportation model, the number of allocations should be equal to m + n, where m is the number of rows and n is the number of columns of the matrix.
(b) Transportation problem is a special case of a linear programming problem.
(c) In case of assignment problem the first step is to make a square matrix by adding a dummy row or dummy column.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 only (d) 2 only

10. The linear programming is used for optimization problems which satisfy the following conditions:
1.Objective function expressed as a linear function of variables
2.Resources are unlimited
3.The decision variables are inter-related and non-negative.
Which of these statement is/are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 only (d) 1 and only

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CHAPTER - 4
ASSIGNMENT

4.1 INTRODUCTION
An assignment problem is a special type of transportation problem in which the objective is to assign a number of origins to an equal number of destinations at a minimum cost (for maximum profit).

Assignment problems differs from **transportation** problem on two grounds:

(i) Matrix must be always square i.e, m = n

(ii) Allocation in each row and column will be only one.

$\text{Min } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}\, x_{ij}$ and all $a_i = 1$ and $b_j = 1$ and $x_{ij} = 0$ or 1

4.2 FORMULATION OF AN ASSIGNMENT PROBLEM
There are n new machines m_i (I = 1, 2, ….., n) which are to be installed in a machine shop. There are n vacant spaces s_i (j = 1, 2, …., n) available. The cost of installing the machine m_i at space S_j is C_{ij} rupees.

Let us formulate the problem of assigning machines to spaces so as to minimize the overall cost.

Let x_{ij} be the assignment of machine m_i to space s_j i.e. Let x_{ij} be a variable such that

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ machine is installed at } j^{th} \text{ space} \\ 0, \text{ otherwise} \end{cases}$$

Since one machine can only be installed at each place, we have

$x_{i1} + x_{i2} + ...x_{in} = 1$ for $m_i (I = 1, 2, 3, ..., n)$

$x_{1i} + x_{2i} + ...x_{ij} = 1$ for $s_i (j = 1, 2, 3, ..., n)$

Thus assignment problem can be stated as follows:

Determine $x_{ij} \geq 0$ (j = 1, 2, 3, ….., n) so as to minimize $(z) = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} x_{ij}$

Subject to the constraints

$\sum_{i=1}^{n} x_{ij} = 1, j = 1, 2, ..., n$ and $\sum_{j=1}^{n} x_{ij} = 1, i = 1, 2, 3, ..., n$

This problem is explicitly represented by the following n × n cost matrix:

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ESE OBJ QUESTIONS

1. Which one of the following statement is NOT correct ?

[ESE - 2000]

(a)Assignment model is a special case of a linear programming problem
(b)In queuing models, Poisson arrivals and exponential services are assumed
(c)In transportation problems, the non- square matrix is made square by adding a dummy row or a dummy column
(d)In linear programming problems, dual of a dual is a primal

2. The assignment algorithm is applicable to which of the following combined situations for the purpose of improving productivity
1. Identification of the sales force market .
2. Scheduling of operator machine
3. Fixing machine –location
Select the correct answer using the codes given below ?

[ESE - 1998]

(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 2

3. Match List - I (Or technique) with List - (II) (Application) and select the correct answer using the codes given below the lists :

List-I
A. Linear programming
B. Transportation
C. Assignment
D. Queuing

List-II
(i) Ware house location decision
(ii) Machine allocation decision
(iii) Product mix decision
(iv) Project management decision
(v) Number of servers decision

[ESE - 2000]

Codes:
(a) A-i, B-ii, C-iii, D-v
(b) A-iii, B-i, C-ii, D-v
(c) A-i, B-iii, C-iv, D-v
(d) A-iii, B-ii, C-i, D-iv

SOLUTIONS

Sol.1. (c)
If supply is greater than demand in the transportation problem a dummy market is added. The non- square matrix is made square in Assignment problems

Sol.2. (c)

Sol.3. (b)

Linear Programming	Product mix decision
Transportation	Warehouse location decision
Assignment	Machine allocation decision
Queuing	Number of servers decision

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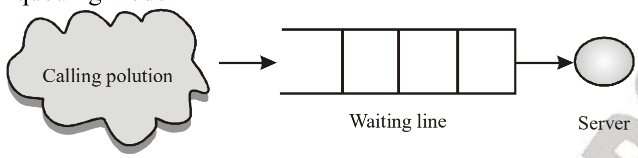
CHAPTER - 5
QUEUING THEORY

5.1 QUEUING THEORY OF WAITING LINE
The goal of queuing model is the achievement of economic balance between the cost of providing services and the cost associated with the wait required for the service. This theory is applicable in service oriented organization machine repairs shops, production system, semi-finished parts waiting for finished operation etc.
A simple but typical queuing model



Typical measures of system performance are sever utilization, length of waiting lines, and delays of customers.

5.2 KEY ELEMENTS OF QUEUING SYSTEMS
Customers: refers to anything that arrives at a facility and requires service, e.g., people, machines, truck, emails.
Server: refers to any resource that provides the requested service, e.g, receptionist, repairpersons, retrieval machines, runways at airport.
1. Calling Population
The population of potential customers may be assumed to be finite or infinite.
Finite Population Model
If arrival rate depends on the number of customers being served and waiting, e.g., model of one corporate jet, if it is being repaired, the repair arrival rate becomes zero.
Infinite Population Model:
If arrival rate is not affected by the number of customers being served and waiting, e.g., systems with large population of potential customers.

5.3 SOME APPLICATION OF WAITING LINE PROBLEM

S. No.	Application area	Arrival	Waiting line	Service facility
1.	Factory	Material/tools	In-process inventory (WIP)	Work stations
2.	Assembly line	Sub-assemblies	WIP	Employees currently
3.	Machine maintenance	Repair tools & equipment	Machine needing repair	Maintenance crew
4.	Airport	Plane	Planes ready to fly	Runway
5.	Bank	Customer	Deposit/withdrawal	Bank employed & computer
6.	Walk-in interview	Job seekers	Applicants	Interviewers
7.	Phone exchange	Dialed number	Caller	Switchboard
8.	Govt. office	Files	Backlog files	Clerk
9.	Post office	Letters	Mailbox	Postal employees
10.	Executive note	Dictation note	Letters to be typed	Secretary

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GATE QUESTIONS

1. For a single server with Poisson arrival and exponential service time, the arrival rate is 12 per hour. Which one of the following rates will provide a steady state finite queue length?

[GATE - 2017]

(a) 6 per hour (b) 10 per hour
(c) 12 per hour (d) 24 per hour

2. At 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 _________

[GATE - 2014]

3. The total number of decision variables in the objective function of an assignment problem of size n × n (n jobs and n machines) is

[GATE - 2014]

(a) 2 (b) 2
(c) 2n - 1 (d) n

4. If there are m sources and n destinations in a transportation matrix, the total number of basic variables in a basic feasible solution is

[GATE - 2014]

(a) m + n (b) m + n + 1
(c) m + n - 1 (d) m

5. 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 poission process and service times are exponentially distributed, the average waiting time in queue in min is

[GATE - 2013]

(a) 3 (b) 4
(c) 5 (d) 6

6. 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

[GATE - 2011]

(a) 10 minutes (b) 20 minutes
(c) 25 minutes (d) 50 minutes

7. Little's law is a relationship between

[GATE - 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

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

[GATE - 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. The number of customers arriving at a railway reservation counter is Poisson distributed with an arrival rte 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

[GATE - 2006]

(a) 3 (b) 3.2
(c) 4 (d) 4.2

10. Consider a single server queuing model with poission arrivals (λ = 4/hour) and exponential service (μ = 4/hour). The number in

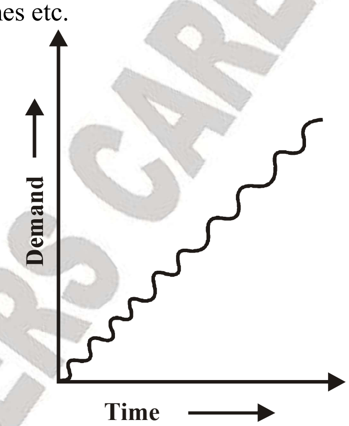
SECTION- B
OPERATION RESEARCH

CHAPTER - 1
FORECASTING

1.1 FORECASTING
Forecasting is the prediction of future sales or demand for a product. It is defined as the estimation of future activities i.e. the estimation of time, quality, quantity of future work. These estimate provide the basis for determining the demand of man power, machines and material in future.
It is a calculated economical analysis.
It is not a guess work but a projection based on passed sales figure and human judgment.

1.2 NEED OF FORECASTING
1. It helps in determining the volume of production and production rate.
2. It forms the basis for production budget, labour budget, material budget etc.
3. It suggest the need for plant expansion
4. It helps in product design & development.
5. It helps in determining price policies.
6. Helps in determining the extent of marketing, advertisement and distribution required.

1.3 TYPES OF DEMAND VARIATION
1. Trend Variation
It shows a long term upward or downward movement in the demand or sales of a product. It shows a regular pattern.
Example. Newspaper, Cellphones etc.



2. Seasonal Variation

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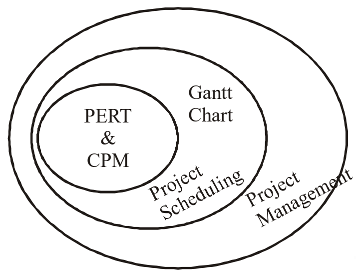
CHAPTER - 2
PERT AND CPM

2.1 PROJECT MANAGEMENT
(Project Planning and Scheduling) – Gantt Chart
Special Scheduling Techniques: PERT and CPM



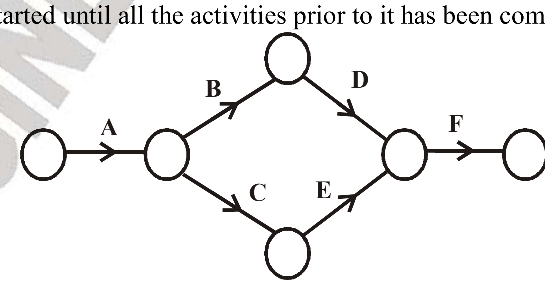
1. Gantt Chart: Is one of the first scientific techniques for project planning and scheduling.
2. CPM: Critical Path Method.
3. PERT: Program Evaluation and Review Technique.
4. Project
Project is a group of Inter – related activities which must be executed in a certain order before the entire task can be completed. The activities are related in a Logical and sequential order in the sense that some activities cannot start until all the activities prior to them are completed. When all the activities are executed then only the project is completed.

5. Event
The event are point in time & denotes the beginning and the end point of an activity. An Event defines an accomplishment occurring at an instantaneous point of time which neither consumes any time nor resources for its completion.

6. Activity
It is a recognizable and identifiable part of a project which consumes time & resources for its completion and may involves physical or mental work.

7. Network Diagram
It represents the sequence of different activities that make a project.

2.1.1 Rules for Network Diagram
1. No activity can be started until all the activities prior to it has been completed.



2. No two or more activities may have the same tail & head event.

CHAPTER - 3
ROUTING &SCHEDULING

3.1 ROUTING

3.1.1 Routing includes the planning

What work shall be done on the material to produce the product or part, where and by whom the work shall be done. It also includes the determination of path that the work shall follow and the necessary sequence of operations which must be done on the material to make the product.

3.1.2 Routing procedure consists of the following steps

The finished product is analyzed thoroughly from the manufacturing stand point, including the determination of components if it is an assembly product. Such an analysis must include:
(i) Material or parts needed.
(ii) Whether the parts are to be manufactured, are to be found in stores (either as raw materials or worked materials), or whether they are-to be purchased.
(iii) Quantity of materials needed for each part and for the entire order.
The following activities are to be performed in a particular sequence for routing a product
1. Analysis of the product and breaking it down into components.
2. Taking makes or buys decisions.
3. Determination of operations and processing time requirements.
4. Determination of the lot size.

3.2 SCHEDULING

3.2.1 Introduction

Scheduling is used to allocate resources over time to accomplish specific tasks. It should take account of technical requirement of task, available capacity and forecasted demand. Forecasted demand determines plan for the output, which tells us when products are needed. The output plan should be translated into operations, timing and schedule on the shop-floor. This involves loading, sequencing, detailed scheduling, expediting and input/output control.

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CHAPTER - 4
BREAK EVEN ANALYSIS

4.1 AGGREGATE PLANNING

It is Dynamic Process and requires continuous updating. We develop an aggregate plan that identifies the best thing to do during each period of the planning horizon to optimize the long term goal of the organization. Then we implement the first passed of the plan. Now we gather more information and update and revise the plan. This is called ``Rolling Horizon``.

4.1.1 Strategies of Aggregate Planning

1. Traditional Approach

(i) Demand unalterable must be satisfied.
(ii) Subcontracting and overtime options modified.
(iii) Work force may vary.

2. Chase Strategy

(i) Production level is adjusted to match demand.
(ii) Hiring and training cost increases
(iii) Productivity losses due to poor moral of workers
(iv) Lay off cost severance pay
(v) Inventory cost decreases

3. Level Strategy

(i)Steady output
(ii)Inventory build up during the pared of row demand and repletion during period of high demand.

4. Pure Strategy

A single alternative is used rather than a combination of alternatives. It Maintain level workforce.

5. Mixed Strategy

A combination of alternatives is sued rather than a single one.

> No need of aggregate planning if demand is continuous.

4.2 BREAK-EVEN ANALYSIS

A. It usually refers to the number of pieces for which a business neither makes a profit nor incurs a loss. In other words, the selling price of the product is the total cost of production of the component.

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ESE OBJ QUESTIONS

1. A part is made from solid brass rod of 38mm diameter and length 25mm .The machining time taken to finish the part is 90minutes and labour rate is Rs 2 per hour .Factor overhead are 50% of direct labour cost .The density of material is 8.6gm per cubic cm and its cost is Rs 1.625 per newton .The factory cost of the part will be **[ESE - 2015]**

(a) Rs 8.40 (b) Rs 4.80
(c) Rs 14.80 (d) Rs 4.90

2. An organization has decided to produce a new product .Fixed cost for producing the product is estimated as Rs 1, 00, 000.Variable cost for producing the product is Rs 100,Market survey indicated that the product selling price could be Rs 200.The break even quantity is **[ESE - 2015]**

(a) 1000 (b) 2000
(c) 500 (d) 900

3. The data for break –even analysis of a product are given as fixed cost is Rs . 10,000; variable cost is Rs 10/ unit, selling price is 15/unit .The break even volume is **[ESE - 2014]**

(a) 2000 (b) 2500
(c) 3500 (d) 4000

4. At break –even point , inventory carrying cost is : **[ESE - 2012]**

(a) Four times the preparatory cost
(b) Three times the preparatory cost
(c) Two times the preparatory cost
(d) Equal to the preparatory cost

5. The break –even point can be lowered by **[ESE - 2011]**

(a) Increasing the fixed costs
(b) Increasing the variable cost
(c) Decreasing the slope of the income line
(d) Reducing the variable cost

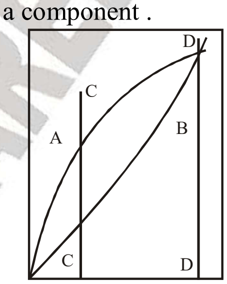
6. Consider the following statements
The break –even point increases
1.If the fixed cost per unit increases
2.If the variable cost per unit decreases
3.If the selling price per unit decreases
Which of these statements is/are correct? **[ESE - 2009]**

(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1 and

7. In the production of a product the fixed costs are Rs , 6, 000/- and the variable cost is Rs 10/- per product .If the sale price of the products is Rs 12/-, the break even volume of product to be made will be **[ESE - 2008]**

(a) 2000 (b) 3000
(c) 4000 (d) 6000

8. The graph shows the result of various quality levels for a component .



Consider the following statements:
1. Curve A shows the variation of value of components
2. Curve B shows the variation of cost of the component
3. Graph is called as fish bone diagram
4. The preferred level of quality is given by line CC
5. The preferred level of quality is given by line DD
Which of these statements are correct? **[ESE - 2002]**

(a) 1, 2, and 5 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 2, 4 and 5

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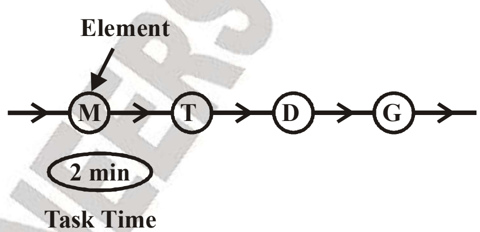
CHAPTER - 5
LINE BALANCING AND MRP

5.1 LINE BALANCING (ASSEMBLING)
5.1.1 Assembly Line Balancing
An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner. The work piece visit stations successively as they are moved along the line usually by some kind of transportation system, e.g, conveyor belt.

5.1.2 Objective in Line Balancing Problem
In an assembly line, the problem is to design the work station. Each work station is designed to complete few processing and assembly tasks. The objective in the design is to assign processes and tasks to individual stations so that the total time required at each work station is approximately same and nearer to that desired cycle time or production rate.
In case, all the work elements which can be grouped at any station have same station time, then this is a case of perfect line balancing. Production flow would be smooth in this case. However, it is difficult to achieve this in reality. When perfect line balancing is not achieved, the station time of slowest station would determine the production rate or cycle time.
It aims at grouping the task or workers. In an effective manner in order to obtain optimum utilization of Man-Power & machine & to minimize ideal time.
Task are grouped so that there total time is preferably equal to or a little lesser than the time available at each work station. This reduce the ideal time.

5.1.3 Advantages
1. Uniform rate of production
2. Less Material handling
3. Less work in process inventory
4. Effective utilization of Man power & machine.
5. Easy production control.
6. Less congestion within production system.

5.1.4 Terminology
1. Work Element



Each job is completed by a set of operations & each operation which is to be performed on the job is called work element or simply element.

2. Task Time
It is the standard time require to complete elemental task. (Ti)

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ASSIGNMENT

1. MRP-II means
(a) Material requirement planning
(b) Manufacturing resource planning
(c) Man requirement planning
(d) Money requirement planning

2. Which one of the following is not a function of production control?
(a) Forecasting (b) Routing
(c) Scheduling (d) Dispatching

3. Which of the following is not an input to the MRP system?
(a) MPS (Master Production Schedule)
(b) Bill of materials
(c) Cost of materials
(d) Inventory status

4. Determination of the sequence of operations to be performed and the allocation of facilities where these operations are to be performed is
(a) Master scheduling
(b) Aggregate planning
(c) Routing
(d) Forecasting

5. A line balancing problem involves 10 workstations having Σt = 24 minutes (shortest is 2.1 minutes, longest is 3.0 minutes). Assuming only one work is located at each station and using longest time as cycle time, the line efficiency is
(a) 60% (b) 80%
(c) 40% (d) 20%

6. In the line and staff type of organization.
(a)Staff would help and line would decide
(b)Staff would decide and they would implement.
(c)Line would decide and staff would implement.
(d)Both line and staff would and implement

SOLUTIONS

Sol. 1. (b)

Sol. 2. (a)
Routing, scheduling and dispatching are the function of production control.

Sol. 3. (c)

Sol. 4. (c)

Sol. 5. (b)

Line $\eta = 1 - BD = \left(\frac{\sum t}{n \times CT}\right) \times 100$

$= \left(\frac{24}{3 \times 10}\right) \times 100 = 80\%$

Sol. 6. (a)

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CHAPTER - 6
WORKSTUDY AND WORK MEASUREMENT

6.1 INTRODUCTION
In practice many layouts has been developed some of them are implemented successfully and discussed subsequent topics.

6.2 PRODUCT LAYOUT
In a product layout, the workstations and equipment are located along the line of flow of the work units. Usually, work units are moved along a flow line which is powered by a conveyor. Work is done in small amounts at each of the workstations on the work unit. This means that to use the product layout the total work must be dividable into small tasks that can be assigned to the workstations. It is also known as Line layout or Flow Shop layout.

1. Work Flow Pattern
(i) Straight line
(ii) U-shape
(iii) L-shape
(iv) Convolute or Serpentine
(v) Comb. Or Dendrite

2. Any changes in **product layout design** or volume etc. normally requires major alternation in the layout.

3. Main Objective
It is to group activities into work-station and achieve the desired output rate with least resources.

4. Suitability
(i) Continuous Product (Assembly & Product line)
(ii) Low variety
(iii) High volume of output

5. Standard Items
Standard Items with stable output rate (demand) with standardized manufacturing routine.

6. Advantages
(i) Low work input
(ii) Reduced material handling costs
(iii) Simplified PPC (Production Planning Control) systems.
(iv) Control Supervision & Accounting low Inspection cost.

7. Limitations of Product Layouts
(i) Lack of process flexibility
(ii) There is duplication of equipments to avoid backtracking
(iii) Lack of flexibility in time – slowest task governs the flow rate.

6.3 PROCESS LAYOUT
In process layout is the floor plan of a plant, which is installed by industrial engineers to improve the efficiency by arranging equipment according to their functions. In this layout, the main idea is

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ESE OBJ QUESTIONS

1. An 8-hour measurement study in a plant reveals that 320 number of units were produced. If idle time = 15% and performance rating = 120%, with allowance = 12% of normal time, the standard time per unit produced will be

[ESE - 2017]

(a) 1.823 minutes (b) 1.714 minutes
(c) 1.645 minutes (d) 1.286 minutes

2. The objective of work measurement is to

[ESE - 2013]

(a) Plan and schedule the production
(b) Estimate the selling price and delivery date
(c) Formulate a proper incentive scheme
(d) All of the above

3. During the time study on a job , the representative time , the rating and allowances are observed to be 0.4 minutes , 120% and 10% of standard time respectively .The normal time and standard time , in minutes, are respectively ?

[ESE - 2010]

(a) 0.48 and 0.533 (b) 0.533 and 0.48
(c) 0.6 and 0.066 (d) 0.7 and 0.8

4. For a confidence level of 95% and accuracy ±5% ,the number of cycles to be times in a time study is equal to

$$\left[K\sqrt{\frac{N\sum X^2-(\sum X)^2}{\sum X}}\right]$$

Where N = number of observations taken; X = X_1 , $_2$…..X_N are individual observations .What is the value of K?

[ESE - 2009]

(a) 10 (b) 20
(c) 30 (d) 40

5. If in a time study, the observed time is 0.75min, rating factor =110% and allowances are 20% of normal time, then what is the standard time?

[ESE - 2009]

(a) 0.82min (b) 0.975min
(c) 0.99 min (d) 1.03min

6. Which one of the following is not a work measurement technique?

[ESE - 2009]

(a) Time study
(b) Work sampling
(c) Motion time data
(d) Micro-motion study

7. A time standard for a data entry clerk is to be set .A job is rated at 120 percent, it takes 30 seconds to enter each record and the allowances are 15% .What is the normal time?

[ESE - 2008]

(a) 25 seconds (b) 30 seconds
(c) 36 seconds (d) 40 seconds

8. Which one of the following statements is not correct?

[ESE - 2008]

(a)Work sampling is a technique if work measurement
(b)Method study is a technique aimed at evolving improved methods
(c)Synthetic data is not a technique covered under predetermined motion time systems
(d) ‘Select ‘ is the first step of method study

9. Which one of the following statements is correct , Standard time is obtained from normal time by adding the policy allowance and ?

[ESE - 2006]

(a) Personal allowances only
(b) Fatigue allowances only
(c) Delay allowances only
(d) Personal ,fatigue and delay allowances

10. Which one of the following is not a technique under Predetermined Motion time System (PMTS)?

[ESE - 2006]

(a) Work factor

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(b) Synthetic data
(c) Stopwatch time study
(d) MTM

11. Match List-I (Symbols in Flowcharts) with List-II (Actions) and select the correct answer using the codes given below the lists :

List-I
A. Parallelogram
B. Diamond shaped box
C. Ellipse
D. Rectangle

List-II
(i) Decision
(ii) Stop
(iii) Processing
(iv) Input /Output

[ESE - 2004]

Codes:
(a) A-iv, B-iii, C-ii, D-i
(b) A-ii, B-i, C-iv, D-iii
(c) A-iv, B-i, C-ii, D-iii
(d) A-ii, B-iii, C-iv, D-i

12. Match List-I (Study) with List-II(Related factors) and select the correct answer using the codes given below the lists :

List-I
A. Job enrichment
B. Job evaluation
C. Method study
D. Time study

List-II
(i) Gilbreth's principles
(ii) Movement of limbs by work factor system
(iii) Herxberg motivators
(iv) Jacques time span of desertion

[ESE - 2000]

Codes
(a) A-ii, B-i, C-iv, D-iii
(b) A-iii, B-iv, C-i, D-ii
(c) A-ii, B-iv, C-i, D-iii
(d) A-iii, B-i, C-iv, D-ii

13. Which one of the following is not a technique of Predetermined Motion Time Systems ?

[ESE - 2000]

(a) Work factor system
(b) MTM
(c) Synthetic data
(d) Stopwatch time study

14. Standard time is

[ESE - 2000]

(a) Normal time +Allowances
(b) (Normal time × Rating) + Allowances
(c) $\left(\frac{\text{Normal time}}{\text{Rating}}\right) + \text{Allowances}$
(d) Normal time + (Allowances ×Rating)

15. In a study to estimate the idle time of a machine , out of 100 random observations. The total random observations required for 95% confidence level and ± 5% accuracy are

[ESE - 2001]

(a) 384 (b) 600
(c) 2400 (d) 9600

16. Which of the following hand-motion belongs to 'Therbligs' in motion study ?
1. Unavoidable delay
2. Preposition
3. Select
4. Reach

Select the correct answer from the codes given below

[ESE - 2000]

(a) 1 and 4 (b) 1 and 2
(c) 1, 2 and 3 (d) 2, 3 and 4

17. Match List-I (Charts) with List-II (operations/information's) and select the correct answer using the codes given below the lists

List-I
A. Standard process sheet
B. Multiple activity chart
C. Right and left hand operation chart
D. SIMO chart

List-II
(i) Operations involving assembly and inspection without machine
(ii) Operations involving the combination of men and machines
(iii) Work measurement
(iv) Basic information of routing
(v) Therbligs

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