INDIAN STATISTICAL INSTITUTE

End-Semester Examination: 2025–26

M. Tech (QROR) – Second Year, Semester-I

Industrial Experimentation

Date: 19.11.2025 **Maximum Marks:** 100 **Duration:** 3 Hours

Instruction: *This question paper consists of three parts.* ***Part A*** *is compulsory and comprises twenty short answer type questions, each carrying* ***one mark****. In* ***Part B****, candidates are required to answer* ***any twelve questions out of fourteen****, with each question carrying* ***five marks****.* ***Part C*** *contains numerical questions; candidates must answer* ***any one question out of two****. F-Table is available on the last page of this question*

Part -A

(*Answers all questions in Part-A, each question carries one mark. Anwer should be maximum one line*)

i) How many generators are required to construct a 2^{8-2}fractional factorial design?

ii) Explain how the error term is estimated in an unreplicated factorial design.

iii) In a 2^kfactorial design, what is the fundamental assumption about the relationship between the response and the factor levels?

iv) What information does the 'defining relation' provide in a fractional factorial design?

v) Identify the problem or flaw in the blocking factorial design given below

Treatment Combination	A	B	Block
1	-1	-1	1
a	1	-1	2
b	-1	1	2
ab	1	1	1

vi) Determine the degrees of freedom associated with the two-factor interactions in a factorial design consisting of two three-level factors and three two-level factors.

vii) In a factorial design, the 'identity element (I)' represents ______________.

viii) The fraction of a full factorial design with $I = +ABC$ usually called as ___________.

ix) In a fractional factorial design alias structure can be found from __________.

x) In a fractional factorial design, ____________ indicates the degree to which the effects are confounded with each other.

xi) A 2^{5-1} fractional factorial design has been created with five factors A, B, C, D and E considering the generator as $BC=ACD$. The resolution of the design will be ____________.

xii) Plackett and Burman design can be used to run a 2^4-factorial design. True/ False.

xiii) ______________ cannot be estimated in a nested design where factor B is nested under A.

xiv) A L_8 orthogonal array is used to estimate the main effects of factor A, B and C, and interaction effects AC and BC. Then __________ number of columns in the array will used for error estimation.

xv) The Number of columns in a $L_{18}\,(2^1 \times 3^7)$ OA is ________________.

xvi) The path of steepest ascent always passes through ______________ point.

xvii) The direction of steepest accent is _______________ to the fitted response.

xviii) In steepest ascent the presence of _________________ term indicates that we are near the optimum.

xix) The total number of nodes and connecting line in a linear graph associated with L_{32} orthogonal array is equal to ___________.

xx) _______________ can not be estimated using a L_{12} OA.

Part-B

(Answer any 12 questions out of 14. Each question carries 5 marks)

1) An experiment was conducted using three factors, ***A***, ***B*** and ***C***, each at two levels. The experimental results of the unreplicated 2^3 factorial design in various treatment combinations are given below:

$(1) = 5;\ a = 4;\ b = 6;\ ab = 3\ ;\ c=1\ ;ac=2,\ bc=4,\ abc= 3$

Calculate the Mean Square (MS) of interaction ***AB***. **[5]**

2) Using the data provided in **Question 1**, determine the type of interaction between factors ***A*** and ***C***—whether it is strong, weak, or no interaction—by employing the appropriate graphical method.

[5]

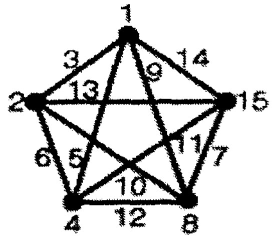
3) Using the experimental data provided in **Question 1**, fit an appropriate regression model and determine the constant (intercept) and the regression coefficients corresponding to factors A and C.

[5]

4) In a 2^2 factorial design, temperature and pressure are considered as two factors. The temperature levels are 62°C (low) and 82°C (high), while the pressure levels are 12 kg (low) and 20 kg (high). Determine the coded values corresponding to the actual conditions of temperature = 68°C and pressure = 15 kg.

[5]

13) In an experimental investigation involving nine two-level factors (A, B, C, D, E, F, G, H, and I), it is required to study the main effects as well as the interactions $A\times B$, $A\times D$, $A\times E$, $B\times D$, and $D\times E$. Using the given linear graph for the L_{16} orthogonal array, allocate the factors and the specified interactions appropriately on the column of the array.



[5]

14) The sums of three replicates from a 2^3 factorial experiment are given below. Draw the interaction plot for the factors A and B (AB interaction).

Treatment combination	Sum of three replication (I+II+III)
(1)	7
a	10
b	11
ab	14
c	12
ac	11
bc	16
abc	12

[5]

Part-C

(Answer any one question from Questions 15 and 16.)

15) An experiment was conducted in a semiconductor fabrication plant to improve yield. Three factors, each at two levels, were studied. The factors and their levels are as follows:

A: Aperture setting (10, 20)
B: Development time (30 s, 40 s)
C: Etch time (14min, 16 min)

A 2^3factorial experiment was conducted with two replications. The observed responses for each treatment combination are given below:

(1) = 2,1 ; a= 6,7 ; b=1,2 ; c= 5,6 ; ab=6,8 ; ac = 3,4 ; bc= 8,9 ; abc = 2,1

a) Assuming higher order interactions are insignificant, determine which factors and interactions are statistically significant.
b) Based on the analysis, provide recommendations for the optimal process operating conditions.
c) Predict the yield at the optimum operating condition.

[10+5+5]

16) To improve the process yield, seven two-level factors — A, B, C, D, E, F, and G in a manufacturing process for an integrated circuit were investigated. The experimenter is interested in estimating the main effects and the interactions: AC, BC, DE, CG, and DF.

(a) Allocate the main effects and specified interactions to an L_{16} orthogonal array by suitably modifying the standard linear graph (SLG) provided below.

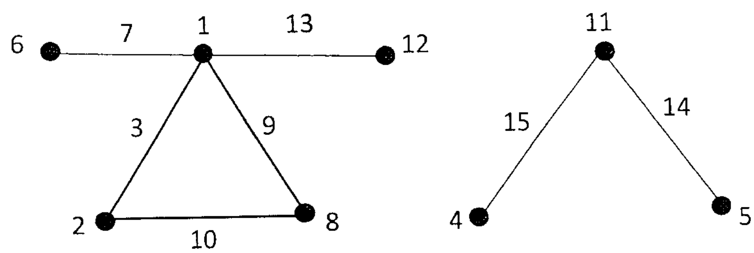


Fig: Standard Linear graph for L16 OA

b) Treating all unassigned columns as error, identify the significant main effects and interactions if the unreplicated responses corresponding to the 16 runs of the L_{16} orthogonal array are as follows:

2, 3, 8, 12, 6, 4, 14, 18, 6, 1, 4, 10, 11, 14, 16, 12.

Table: L16 Orthogonal Array

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

[10+10]

5) An experiment is to be conducted with four factors—A, B, C, and D—each at two levels. However, only 8 runs can be performed in a single batch. Considering the batch as a block, set up an unreplicated full factorial design accordingly.

[5]

6) Why is a split-plot design preferred over a completely randomized factorial design in certain experimental situations? Explain your answer with a suitable real-life example.

[5]

7) Explain the concepts of Resolutions *III*, *IV*, and *V* in fractional factorial designs, illustrating each with the alias structures for a design involving five factors — *A*, *B*, *C*, *D*, and *E*.

[5]

8) Explain the concept of partial confounding and illustrate it with a suitable example of a factorial design.

[5]

9) An experimenter plans to conduct an experiment with ten two-level factors (*A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, *I*, and *J*). The objective is to study all the main effects and the interaction effects *AD*, *AG*, *GH*, *DC*, *BC*, *AC*, and *BE*. Determine the minimum number of experimental runs required for this study and illustrate the corresponding Required Linear Graph (RLG).

[2+3]

10) An experimenter plans to conduct an experiment with four two-level factors *A*, *B*, *C*, and *D* — using a 2^{4-1} fractional factorial design with the generator $B = ACD$. Show the complementary fraction of this design.

[5]

11) Construct a 2^{5-2} fractional factorial design for five factors — *A*, *B*, *C*, *D*, and *E* — using the generators $D = AB$ and $E = AC$. Determine the resolution of the resulting design.

[5]

12) A manufacturing engineer is studying the dimensional variability of component that is produced on two machines. Each machines have two spindles. Two components are randomly selected from each spindle. The results are shown below. Determine the contribution of variation by the machine and by the spindle.

	Machine-1		Machine-2	
Spindle	1	2	1	2
	2	1	2	0
	1	0	1	2

[5]

Table V. Critical values for F-test for Alpha = 0.05

Denominator Degrees of Freedom	Numerator Degrees of Freedom 1	2	3	4	5	6	7	8	9	10
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54	241.88
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83