Chapter 3: Design of Experiments and Taguchi Methods

Repeated Questions:

1. DOE Basics:

- **Q.** Define factors, levels, and response in DOE with an example. / Define DOE and enlist its components. **(WINTER 2022, 7 Marks; SUMMER 2023, 3 Marks OR; SUMMER 2025, 7 Marks; WINTER 2025, 7 Marks – "Define DOE and enlist the components of DOE. Discuss Taguchi Quality Loss Function.")**

Answer:

Definition of DOE:

Design of Experiments (DOE) is a systematic statistical method to plan, conduct, analyze, and interpret experiments so that valid and objective conclusions about the effect of input variables on an output can be drawn.

Components of DOE:

Term	Definition	Example (Casting Process)
Factor	An independent input variable that is deliberately varied in an experiment.	Temperature, pressure, cooling rate
Level	A specific value or setting of a factor.	Temperature levels: 200°C, 250°C, 300°C
Response	The output or quality characteristic measured from the experiment.	Surface roughness, hardness, tensile strength

Additional DOE Terminology:

- **Treatment:** A specific combination of factor levels.
- **Run:** A single trial of the experiment.
- **Replication:** Repeating a run to estimate experimental error.
- **Blocking:** Grouping experimental units to reduce nuisance variation.
- **Example:** To study the effect of temperature (factor) at three levels (150°C, 200°C, 250°C) and pressure (factor) at two levels (1 bar, 2 bar) on surface roughness (response) of a casting.

- **Q.** What is DOE? Enlist the types/Steps in experimental design. **(SUMMER 2022, 4 Marks; WINTER 2023, 3 Marks OR; WINTER 2024, 4 Marks OR; WINTER 2025, 3 Marks; SUMMER 2026, 4 Marks – "Describe experimental design with a suitable example.")**

Answer:

- **Definition:** DOE is a statistical approach for planning experiments to obtain valid data and analyze the effects of multiple factors on a response with minimum runs.

Steps in Experimental Design:

Define the objective and identify the response variable.

Identify factors and levels that may affect the response.

Select an experimental design (e.g., full factorial, fractional factorial, Taguchi).

Conduct the experiment and collect data (randomize runs, use replication).

Analyze the data using ANOVA, regression, or main/ interaction effects.

Validate the model with confirmation runs.

Draw conclusions and recommend optimal settings.

- **Types of DOE:** Full factorial design, fractional factorial design, Taguchi orthogonal arrays, response surface methodology, randomized block design.

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2. Taguchi Method:

- **Q.** Discuss the Taguchi Quality Loss Function. **(WINTER 2022, 7 Marks; SUMMER 2023, 4 Marks OR; WINTER 2024, 4 Marks; WINTER 2025, 7 Marks – combined with DOE components)**

Answer:

- **Definition:** The Taguchi Quality Loss Function (QLF) quantifies the economic loss caused by deviation of a quality characteristic from its target value, even if the deviation is within specification limits.

Key Concept:

- **Traditional view:** No loss if within specification limits (goal post mentality).
- **Taguchi view:** Any deviation from target causes loss; loss increases quadratically as deviation increases.

Formula (Nominal-the-Best):

$L(y)=k(y-m)^2$

Where:

L(y) = quality loss in monetary units

y = measured quality characteristic

m = target value

k = cost coefficient (determined from loss at specification limit)

Graphical Representation:

A parabola with minimum loss (zero) at the target value.

Loss increases as the characteristic deviates in either direction.

Types of QLF:

- **Nominal-the-Best:** Target is a specific value (e.g., shaft diameter).
- **Smaller-the-Better:** Lower is better (e.g., wear, noise).
- **Larger-the-Better:** Higher is better (e.g., strength, life).

Benefits:

Encourages reducing variation around the target, not just meeting specifications.

Links quality to economic loss, making quality improvement financially measurable.

Drives continuous improvement and robust design.

Diagram Description: A parabolic curve with the horizontal axis representing quality characteristic and vertical axis representing loss. The curve touches zero at the target value and rises symmetrically on both sides, with specification limits marked where loss begins to increase sharply.

- **Q.** Discuss various steps in the Taguchi method. / Enlist the steps for achieving robustness. **(SUMMER 2022, 3 Marks OR; SUMMER 2023, 3 Marks; WINTER 2025, 4 Marks – "Discuss about Taguchi approach in context to DOE")**

Answer:

Steps in the Taguchi Method:

Identify the objective and quality characteristic (response).

Select control factors (design parameters) and their levels.

Identify noise factors (uncontrollable variables) and their levels.

Choose an orthogonal array (e.g., L9, L18) based on factors and levels.

Conduct experiments as per the array and record responses.

Analyze results using Signal-to-Noise (S/N) ratio and ANOVA.

Determine optimal factor levels that maximize S/N ratio and minimize variation.

Conduct confirmation experiment to validate the optimal settings.

- **Robustness:** Achieved by selecting control factor levels that make the response insensitive to noise factors.

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3. Robust Design:

- **Q.** What do you understand by robust design? How do Taguchi techniques help achieve it? **(WINTER 2022, 4 Marks OR; WINTER 2024, 7 Marks; SUMMER 2025, 4 Marks OR; SUMMER 2026, 3 Marks – "Explain concept of Robust design in context to DOE")**

Answer:

- **Definition:** Robust Design is a design approach that makes a product or process insensitive to variations in noise factors (environmental, manufacturing, or usage variations) while maintaining performance.

Concept:

- **Traditional design:** Control variation by tightening tolerances (expensive).
- **Robust design:** Reduce the effect of variation without eliminating causes.

How Taguchi Techniques Help Achieve Robustness:

- **Orthogonal Arrays:** Efficiently study many factors with fewer experiments; identify main effects and interactions.
- **Signal-to-Noise (S/N) Ratio:** Measures quality as a ratio of mean performance to variability; maximizing S/N achieves robustness.
- **Parameter Design:** Select optimal levels of control factors to minimize sensitivity to noise factors.
- **Tolerance Design:** If parameter design is insufficient, tighten tolerances on critical factors only.
- **Quality Loss Function:** Provides an economic measure of deviation from target; guides improvement priorities.
- **Two-Step Optimization:** First maximize S/N ratio (reduce variability), then adjust mean to target.
- **Confirmation Runs:** Validate that the robust design performs consistently under noise conditions.
- **Benefits:** Lower manufacturing cost, higher reliability, reduced warranty costs, and consistent product performance.

Other Important Questions:

1. DOE Terms, Importance and Factorial Designs:

- **Q.** Define following terms: (i) ANOVA (ii) Response (iii) Factorial Design. **(SUMMER 2022, 3 Marks)**

Answer:

- **ANOVA (Analysis of Variance):** A statistical technique to test whether means of two or more groups differ significantly by partitioning total variation into components due to factors and random error.
- **Response:** The output variable or quality characteristic measured in an experiment (e.g., strength, surface finish, yield).
- **Factorial Design:** An experimental design where all possible combinations of factor levels are tested to study main effects and interactions (e.g., 2 factors at 2 levels = 2^2=4 runs).

- **Q.** What is the difference between a run and a replication in DOE? What is the purpose of replication? **(SUMMER 2022, 4 Marks OR)**

Answer:

Aspect	Run	Replication
Definition	A single trial or observation of a treatment combination	Repetition of an entire run or treatment combination
Purpose	To collect one data point for a treatment	To estimate experimental error and increase precision
Number	One per treatment combination (unless replicated)	Multiple independent repetitions of a run
Effect on Error	Does not provide an estimate of pure error	Provides an independent estimate of experimental error

Purpose of Replication:

Estimates experimental error (pure error).

Increases precision of effect estimates.

Improves the power to detect significant effects.

Allows validation of results and reduces the impact of random variation.

- **Q.** What is the importance of DOE? **(WINTER 2024, 3 Marks)**

Answer:

Importance of DOE:

Identifies significant factors affecting a response with minimum experiments.

Studies interactions between factors, which one-factor-at-a-time experiments miss.

Reduces cost and time by optimizing the number of runs.

Provides a basis for robust design and process optimization.

Enables data-based decision making and avoids trial-and-error approaches.

- **Q.** Elaborate Full factorial and Fractional factorial design. **(SUMMER 2026, 7 Marks)**

Answer:

Full Factorial Design:

- **Definition:** An experimental design that includes all possible combinations of factor levels.
- **Number of runs:** Runs=L^k, where L = number of levels, k = number of factors.
- **Example:** 3 factors at 2 levels → 2^3=8 runs.
- **Advantages:** Estimates all main effects and interactions; complete information.
- **Disadvantages:** Number of runs increases rapidly with factors; costly and time-consuming for many factors.
- **When to use:** Few factors (≤4) and when interactions are important.

Fractional Factorial Design:

- **Definition:** A design that uses only a carefully selected subset of the full factorial runs.
- **Number of runs:** Runs=L^{k-p}, where p is the fraction reduction.
- **Example:** 2^{3-1} design uses 4 runs instead of 8.
- **Advantages:** Efficient for screening many factors; reduces cost and time.
- **Disadvantages:** Some interactions are confounded (aliased) with main effects or other interactions; loss of information.
- **When to use:** Many factors (≥5) and when higher-order interactions can be assumed negligible.

Comparison Table:

Feature	Full Factorial	Fractional Factorial
Runs	All combinations	Subset of combinations
Interactions	All estimable	Some confounded
Cost/Time	High	Low
Use	Few factors, detailed study	Many factors, screening

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2. Risk Assessment:

- **Q.** Discuss the Risk Assessment procedures in design. **(WINTER 2025, 4 Marks)**

Answer:

Risk Assessment in Design:

- **Identify Potential Failure Modes:** Use techniques like FMEA, FTA, and HAZOP to list possible failure modes in design.
- **Assess Severity and Probability:** Rate each failure mode for severity of consequences and likelihood of occurrence.
- **Evaluate Detection Capability:** Determine how easily the failure can be detected before reaching the customer.
- **Calculate Risk Priority Number (RPN):** RPN=Severity×Occurrence×Detection.
- **Prioritize and Mitigate:** Focus on high-RPN items; implement design changes, safety factors, or redundancy.
- **Re-evaluate and Document:** After mitigation, recalculate RPN and document the risk assessment for traceability.
- **Tools Used:** DFMEA (Design FMEA), Fault Tree Analysis, Risk Matrix, and Design Reviews.
