Quality Engineering and Experimental Design

References
• Montgomery, Ch. 1
• DeVor, Ch. 15

Outline

√ Quality engineering
• Design of experiments concept
Quality Engineering Phases

• Quality engineering deals with variations and consistency of quality characteristics

• Three phases
  – off-line quality design
  – on-line quality monitoring & control
  – quality improvement

Off-Line Quality Design

• Design of experiments and modeling
  – understand the process and its factors

• Robust design
  – measure quality and its variation
  – consist of parameter design, tolerance design
Design of Experiments

- The values of several parameters are changed simultaneously and their effects are estimated efficiently based on statistical theory.

- The results of the experiment are used to build a model of how the process outputs are affected by changes in process inputs.

\[ \text{a) Full Factorial} \]
\[ \text{b) Fractional Factorial} \]

On-line Quality Monitoring & Control

- Monitoring
  - statistical process control (SPC)

- Control
  - automatic process control (APC)
  - feed-forward process control
On-line Quality Monitoring and Control

- **APC**
  - compensate for deviation
  - inexpensive measurement and adjustment
  - continuous process sampling
  - high time correlation

- **SPC**
  - remove the special cause
  - expensive measurement and adjustment
  - discrete parts sampling
  - low time correlation

Quality Improvement

- Simple tools or management solutions
  - cause-and-effect analysis
  - Pareto analysis
  - quality circle

- Statistical methods
  - Response surface method
Response Surface Method

- Determine the optimal response based on
  - experimental design
    - central composite design
    - EVOP
    - steepest ascent
  - regression models

Design of Experiments Course Focus

A unified linear modeling approach to discuss each topic and their inter-relationship

- Design of experiments
  - ANOVA
  - Factorial design
  - Fractional factorial design
- Regression models
- Response surface method
Quality Management Course Focus

A balanced focus on both statistical techniques and quality management concepts

- Design of experiments
  - ANOVA
  - Factorial design
  - Fractional factorial design
  - Robust design
- Statistical process control
- Quality improvement
- Service quality

Outline

- Quality engineering
  ✓ Design of experiments concept
DOE and RSM

• Design of experiments
  – Conduct experiments to explore the factor effects

• Response Surface Method
  – Conduct experiments to search for the optimal response

Statistical Design of Experiments

• The values of several parameters are changed simultaneously and their effects are estimated efficiently based on statistical theory.
  – A treatment combination, run, or design point is a combination of factor settings (or levels) under which one experiment is performed.
  – An experimental design is a group of treatment combinations.

• The results of the experiment are used to build a model of how the process outputs are affected by changes in process inputs.

• The objective may either be confirmation or exploration.

• In the exploration (screening) stage, the goal is to discover the direction of change which may lead to improvements in both the quality and productivity of a product or process.
Purpose of Design of Experiments

- Determining which variables are most influential on the response $y$
- Determining where to set the influential $x$’s so that $y$ is almost always near the desired nominal value
- Determining where to set the influential $x$’s so that variability in $y$ is small
- Determining where to set the influential $x$’s so that the effects of the uncontrollable variables $z_1, z_2, \ldots, z_q$ are minimized

Problem with a One-variable-at-a-time Experiment

- It generally gives rise to a large number of tests.
- It fails to recognize variable interactions.
Failure of One-variable-at-a-time Experiment

Using Experimentation to Optimize a Process
Dealing with Noise in DOE

• Blocking
  – block known sources of variation so that their effects are absent from the comparisons we make within an experiment

• Randomization
  – randomize unknown sources of variation so that they are uniformly and randomly distributed across the trials conducted

• Replication
  – replicate the same test conditions will provide comparisons that directly measure the amount of variation/experimental error

• Confirmation
  – conduct additional trails to verify the improvement opportunities revealed from the experiment

An Example of Blocking and Randomization

Compare two cutting tool life difference

<table>
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<th>y (Cutgo-T)</th>
<th>y (Nork-V)</th>
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<td>20R</td>
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*L and R refer to the left half and right half of a bar, respectively.
Types of Experimental Design

Parallel-type approach

- One-factor design (2 levels)
  - Hypothesis testing, confidence interval (randomized design)
  - Paired comparison (block design)
- One-factor design (k levels)
  - Completely randomized design
  - Randomized complete block design
  - Two block design (Latin square)
- Two-factor design

Sequential-type approach

- One-factor design (2 levels)
- Response surface method design
  - Central composite design
  - Box-Behnken design
  - Computer-aided design (D, G optimal design)
  - EVOP
  - Steepest ascent

Graphical Representation of Some Experimental Designs

- a) Full Factorial
- b) Fractional Factorial
- c) Central composite
- d) Box-Behnken
- e) Robust
- f) Nested
Guidelines for Designing an Experiment

- Recognition of and statement of the problem
- Choice of factors, levels, and ranges
- Selection of the response variable
- Choice of experiment
- Statistical analysis of the data
- Conclusions and recommendations

Good Experimental Design

1. The ability to deal simultaneously with both qualitative (categorical) and quantitative factors/variables.
2. The ability of an experimental design to observe the effects of changing factors individually (all other factors held constant) but at the same time being able to do this at several different combinations of the other factors so that factor interdependencies can be properly revealed.
3. The ability of the experimental design to deal with the forces of nuisance variation, explicitly identifiable or not, through the techniques of blocking and randomization.
4. The ability of the experimental design to observe the forces of experimental: error/system variability directly so that comparisons of performance can be made in light of the magnitude of system noise. Replication of tests provides us with the ability to do this.
5. Explicit recognition of the relationship between the proposed mathematical model and the experimental design that responds to that model.
6. Awareness of the notion of model building and the sequential and interactive nature of experimentation. In this regard, the ability to employ experiments that serve as building blocks, one upon the other, is important.
7. Recognition of the concepts of Taguchi, including parameter/robust design in the use of designed experiments for product process design and improvement.
Using Statistical Techniques in Experimentation

- Use your nonstatistical knowledge of the problem
- Keep the design and analysis as simple as possible
- Recognize the difference between practical and statistical significance
- Experiments are usually iterative

History of Statistical Design

- First era: Fisher in 1920
  - agricultural experiments
  - statistical design and analysis
- Second era: Box and Wilson in 1950
  - response surface methodology
- Third era: Taguchi in 1970
  - robust design
- Fourth era: Renewed general interest in 1990
  - practical use by both researchers and practitioners
  - formal education in statistical experimental design