CSCE 554 – Engineering Experiments

Chapter 1 – Introduction to DOE

1. Introduction to DOE

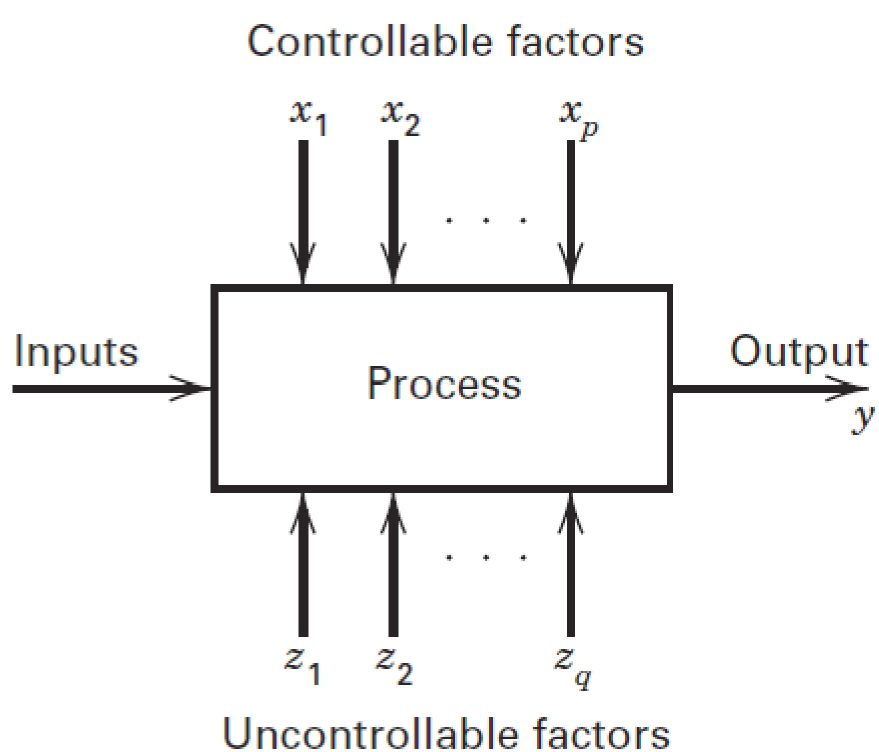
- The strategy of experimentation
- Some basic principles and terminology

1.1 Strategy of Experimentation

- Experimentation is an important part of scientific and engineering investigation
  - New product design; Manufacturing process improvement; Service operations improvement
  - Can be used to lower product cost, reduce product development time, improve product reliability
- By observing a system we can learn a lot about it
  - Can formulate theories or hypotheses on what makes the system work
- But to understand the cause-and-effect relationships, we need to purposely change input variables under study (while controlling the remaining variables) and observe system output → Controlled Experiments
  - Can prove the theories are correct

1.1 Strategy of Experimentation

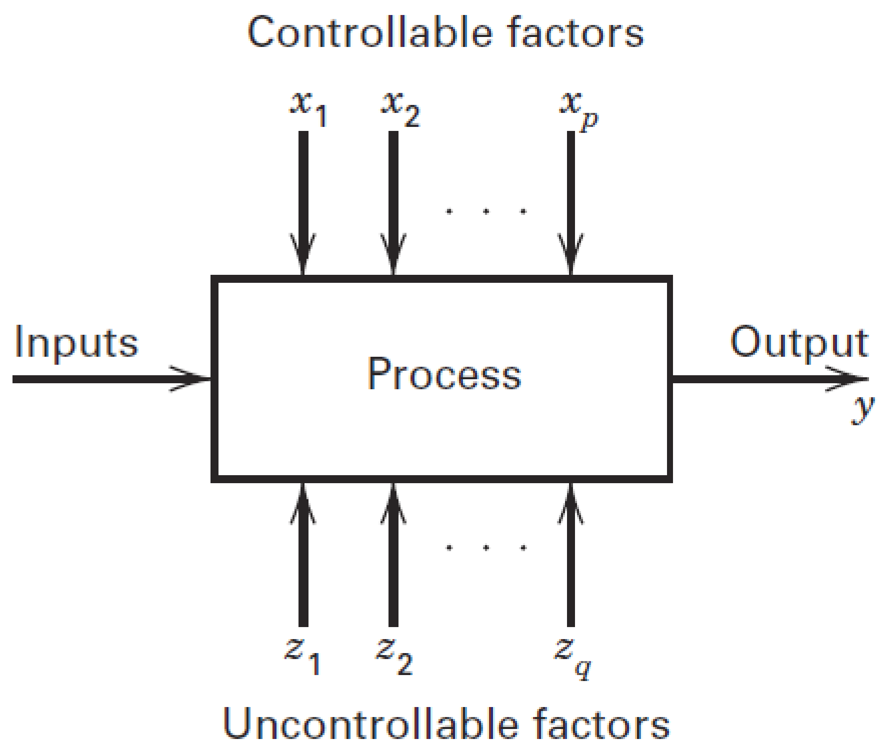
- Experiment
  - a series of tests in which we make purposeful changes to input variables so that we may identify and quantify the changes in the process output
- In this course we will learn methods to
  - Plan, design and conduct experiments
  - analyze resulting data to obtain valid and objective conclusions



1.1 Strategy of Experimentation

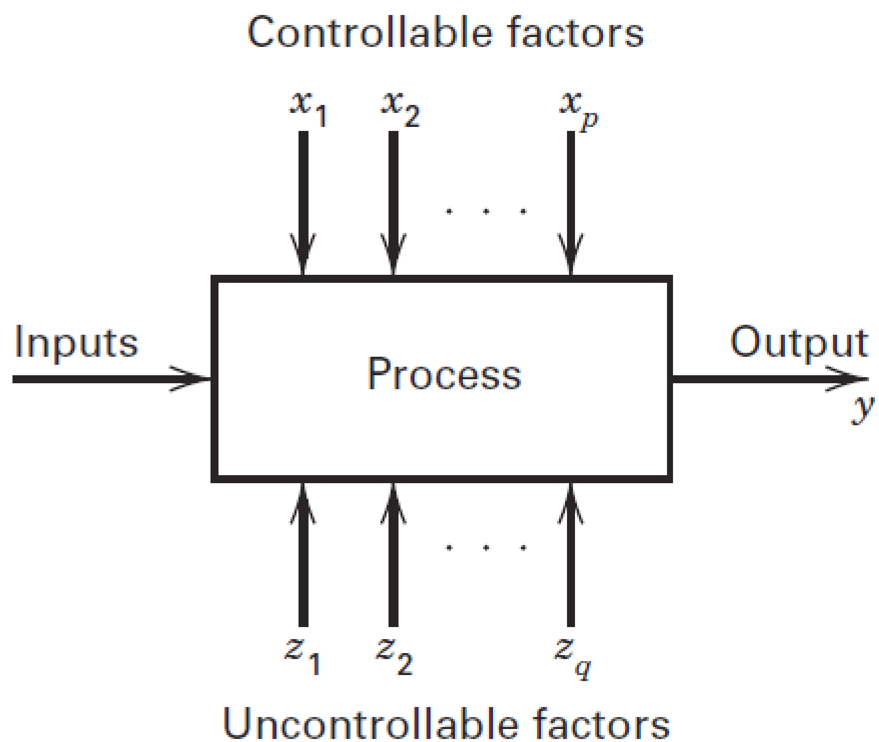
- Factor (input)
  - a variable studied
- Response (output)
  - Experimental outcome
- Effect of a factor
  - Amount of change in the response
- Levels of a factor
  - To study the effect, two or more values of the factor must be tested
- Treatment
  - a combination of factor levels in each test.
- Experimental unit
  - Material/condition at which each experiment is conducted

- Objectives in experiments
  - Determine which factors x are most influential on response y (Characterization)
  - Determine where to set x's so that y is almost always near a desired value (Optimization)



Systems perspective

- A system can be a product or process.
  - A product can be one developed in engineering, biology, or the physical sciences.
  - A process can be a manufacturing process, a process that describes a physical phenomenon, or a non-physical process (business or biology systems)
- Example: Study the efficiency of a payroll operation.
  - Factors: number of supervisors, number of clerks, method of bank deposit, level of automation.
  - Response: total annual cost.



Responses

- Experimental outcome or observation. May be multiple responses. Can be continuous or discrete
  - Continuous: force measurement for opening a door [lbf]
  - Discrete: counts [# of defects], ordinal categories [easy, normal, hard]
- Choice of Response: All vested interests (user, producer, marketing department) must be represented
  - Brainstorming session, using Fishbone diagrams
  - Ex: Producing a popcorn that sells more: Key qualities to the consumer? Fluffiness? Color? Taste? Percent popped?
- Objective of optimization according to response
  - Nominal-the-best, larger-the-better or smaller-the-better.

Factors: Levels

- Independent variables studied in the experiment. Can be continuous or discrete
  - Continuous: temperature, time or pressure. [e.g., 130 and 160 deg C as the levels of temperature]
  - Discrete: nominal categories (resin from Suppliers A&B, operation mode)
- To study the effect of a factor on the response 2 or more levels of the factor should be studied
  - Linear effect: 2 levels sufficient
  - Quadratic effect: 3 levels or more needed

Factors: Identify potential interactions

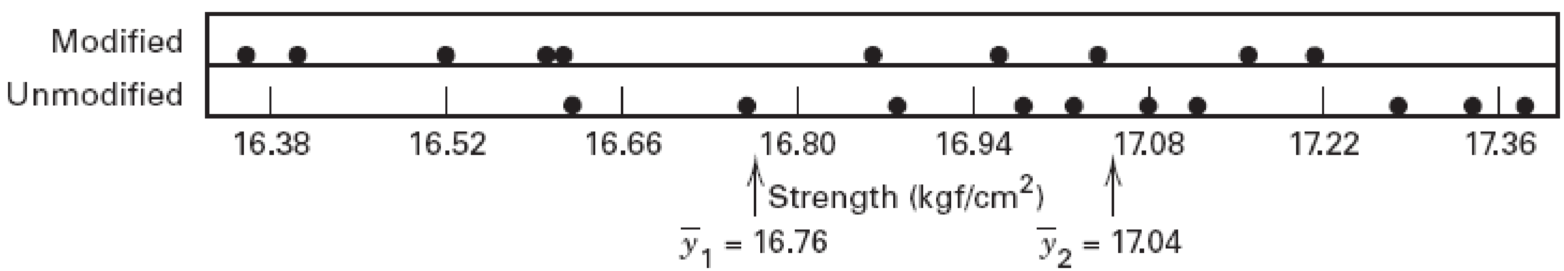
- In planning the experiment, it is important to identify potential synergy between factors
- Interaction between factors: Synergy between factors
  - combined effect of factor levels that is above and beyond the sum of the individual effects of the factors
  - Example: Sales of a product in a store. Adding a certain amount of shelf space adds 10 units of sales. Adding a certain amount of money to promotion adds 8 units of sales. Add both shelf space and promotion $s → 18 units of sales?
  - If the gain is > 18 units → Positive interaction

Types of experimental problems

- *Treatment Comparisons.* compare several treatments and select the best ones.
  - Compare six barley varieties; are they different in terms of yield and resistance to drought? If they are indeed different, how are they different and which are the best?
- *Factor Screening*. If there is large number of variables but only a small number of them is important
- *Process Characterization*: Once a smaller number of factors is identified as important, study their effects thoroughly (influence of factors).
- *Process Optimization:* How does changing the setting of the factors improve the response?
  - Maximize throughput of an assembly plant, minimize amount of scrap in a stamping operation

Example: Tension Strength Experiment

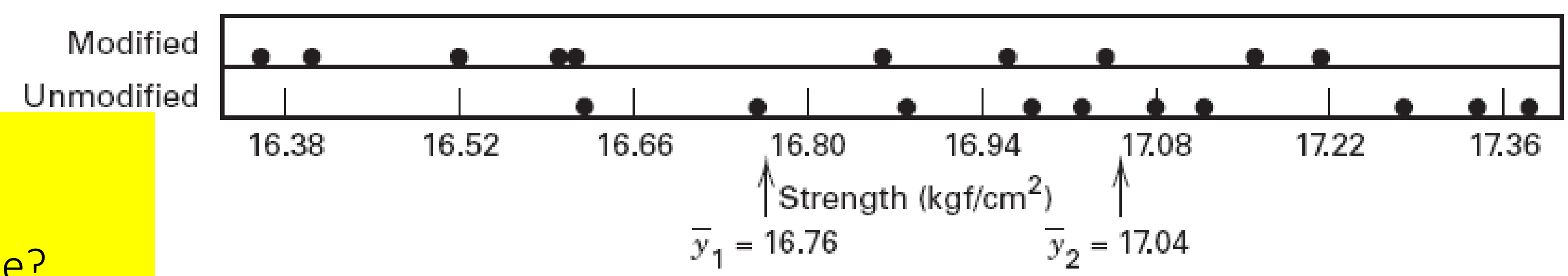
- Study the effect of two formulations on the strength of a cement: *treatment comparison*
  - Adding a polymer latex emulsion vs. adding no emulsion
  - Is there any difference between the strength?
- Experiment
  - Subject a number of samples to each formulation.
  - Use average strength of samples to determine if there is any difference between formulations



■ FIGURE 2.1 Dot diagram for the tension bond strength data in Table 2.1

Example: Tension Strength Experiment

- Study the effect of two formulations on the strength of a cement: *treatment comparison*
  - ❑Adding a polymer latex emulsion vs. adding no emulsion
  - ❑Is there any difference between the strength?
- Experiment
  - ❑Subject a number of samples to each formulation.
  - ❑Use average strength of samples to determine if there is any difference between formulations
    - o Is the difference in averages large enough to state formulations are different?



URE 2.1 Dot diagram for the tension bond strength data in Table 2.1

Factors?
Levels?
Response?
Treatments?
Exp unit?

Example: Tension Strength Experiment

- Some questions related to the design and analysis of the experiment:
  - How many samples should be tested? **(Replication)**
  - What difference in the average observed difference should be considered as important? (**Statistical significance)**
  - How should the experimental units be assigned to the treatments and in which order the should the treatments be applied? (**Randomization**)

1.3. Basic Principles

- Data from the experiment are subject to "Experimental Errors"
  - Errors are variations due to things we could not control during the experiment
  - Errors are modeled as random variables; normal with 0 mean and variance σ^2 . Statistical methods are used to analyze experimental data.
- 3 fundamental tools in DOE to deal with variation
  - Replication
  - Randomization
  - Blocking

Replication

- Replication is an independent repeat of each factor combination
  - ❑ repeated experiment (n times) under the same controlled setting
- Useful to
  - ❑ (1) estimate the experimental error σ^2 → used to determine whether the observed difference in the data is statistically significant
  - ❑ (2) Decrease variance of estimates and increase the power to detect significant differences:

  → variance of sample mean σ^2/n

Randomization

- Run all the tests in the experiment in random order:
  - Allocation of experimental units to the treatments and the order in which the treatments are applied
- It provides protection against variables that are unknown to the experimenter (environmental, ‘lurking’, factors) but may impact the response
- Statistical methods assume that the observations are independently distributed random variables.
  - Randomization makes this assumption valid.

Blocking

- Blocking is controlling the factors that are not of primary interest ("nuisance factors") but that if uncontrolled will add to the variability in the data and obscure the true effects of the factors that are of interest
  - Nuisance factors: factors that may influence the experimental response; but in which we are not interested (e.g., batches is a nuisance factor)
  - Block is a group of homogeneous experimental units (E.g.: days, batches, operators)

- Run and compare treatments within the same block (Use randomization within blocks.)
  - It can eliminate block-block variation and reduce variability of treatment effects estimates.
- Chapter 4 and chapter 7

Illustration: Typing Experiment

- Two keyboards (A and B, treatments) are to be compared for typing efficiency. 6 different manuscripts (1-6, experimental units) are given to the **same** typist (typing skill, control variable)
- Several designs (orders of test sequence) considered
- Design 1 (non-randomized)

  1. A,B, 2. A,B , 3. A,B, 4. A, B, 5. A, B, 6. A, B

  - After typing with keyboard A the typist will be familiar with manuscript and when it is typed on keyboard B it will be faster →
  - learning is a lurking factor
  - the effect of learning confounded with the effect of keyboard
- Design 2: randomizing the order of treatments
  - to reduce the learning effect to unfairly help keyboard B

  1. A,B, 2. B,A, 3. A,B, 4. B, A, 5. A, B, 6. A, B

Illustration: Typing Experiment

- Manuscripts can vary in length and difficulty→ treat each manuscript as a “block”
  - ❑Compare two keyboards (treatments) within the **same** manuscript (block)
  - ❑Incorporated in the analysis

Example

- Consider your thesis... Is it?
  - ❑ Factor Screening
  - ❑ Optimization
  - ❑ Confirmation
  - ❑ Discovery
  - ❑ Robustness