Design and Analysis of Engineering Experiments

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Design of Experiments
Chapter 1

- Goals of the course
- An abbreviated **history** of DOE
- Some basic **principles** and terminology
- The **strategy** of experimentation
- **Guidelines** for planning, conducting and analyzing experiments

Introduction to DOE

- An **experiment** is a test or a series of tests
- Experiments are used widely in the engineering and physical sciences
  - Process characterization & optimization
  - Evaluation of material properties
  - Product design & development
  - Component & system tolerance determination
- "All experiments are designed experiments, some are poorly designed, some are well-designed"

The Goal

- Reduce **time** to design/develop new products & processes
- Improve **performance** of existing processes
- Improve **reliability** and performance of products
- Achieve product & process **robustness**
- **Evaluation** of materials, design alternatives, **setting** component & system tolerances, etc.

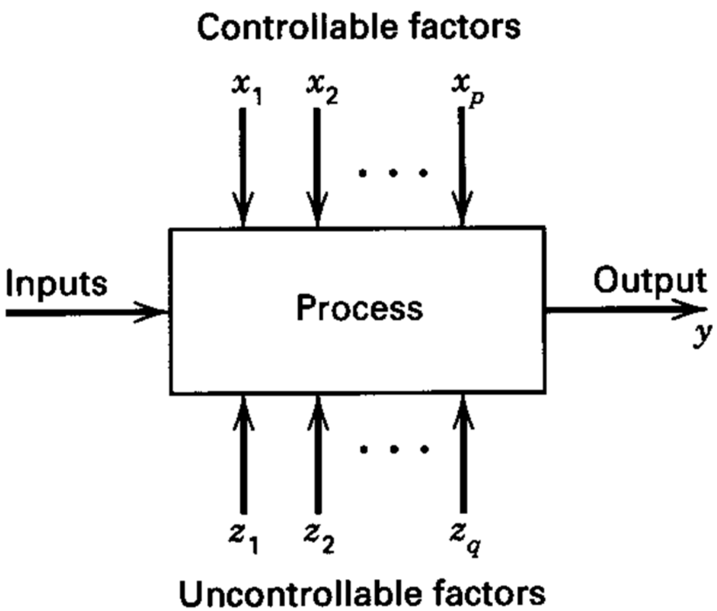


Figure 1-1 General model of a process or system.

Four Eras in the History of DOE

- The **agricultural** origins, 1918 – 1940s
  - R. A. Fisher & his co-workers
  - Profound impact on agricultural science
  - Factorial designs, ANOVA

- The **first industrial** era, 1951 – late 1970s
  - Box & Wilson, response surfaces
  - Immediacy and sequentiality
  - Applications in the chemical & process industries

Four Eras in History of DOE (cont)

- The **second industrial** era, late 1970s – 1990
  - Quality improvement initiatives in many companies
  - Taguchi and robust parameter design, process robustness

- The **modern** era, beginning circa 1990

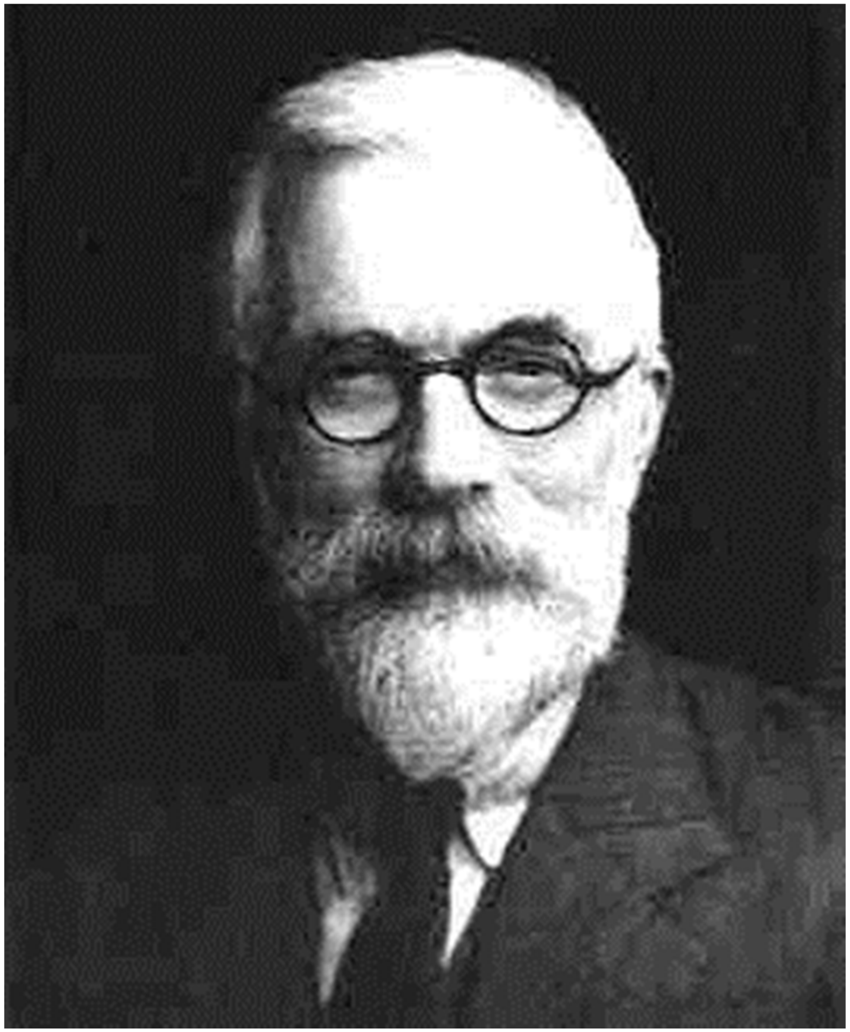
William Sealy Gosset (1876-1937)

Gosset's interest in barley cultivation led him to speculate that design of experiments should aim, not only at improving the average yield, but also at breeding varieties whose yield was insensitive (robust) to variation in soil and climate.

Gosset was a friend of both Karl Pearson and R.A. Fisher, an achievement, for each had a monumental ego and a loathing for the other.

Gosset was a modest man who cut short an admirer with the comment that "Fisher would have discovered it all anyway."

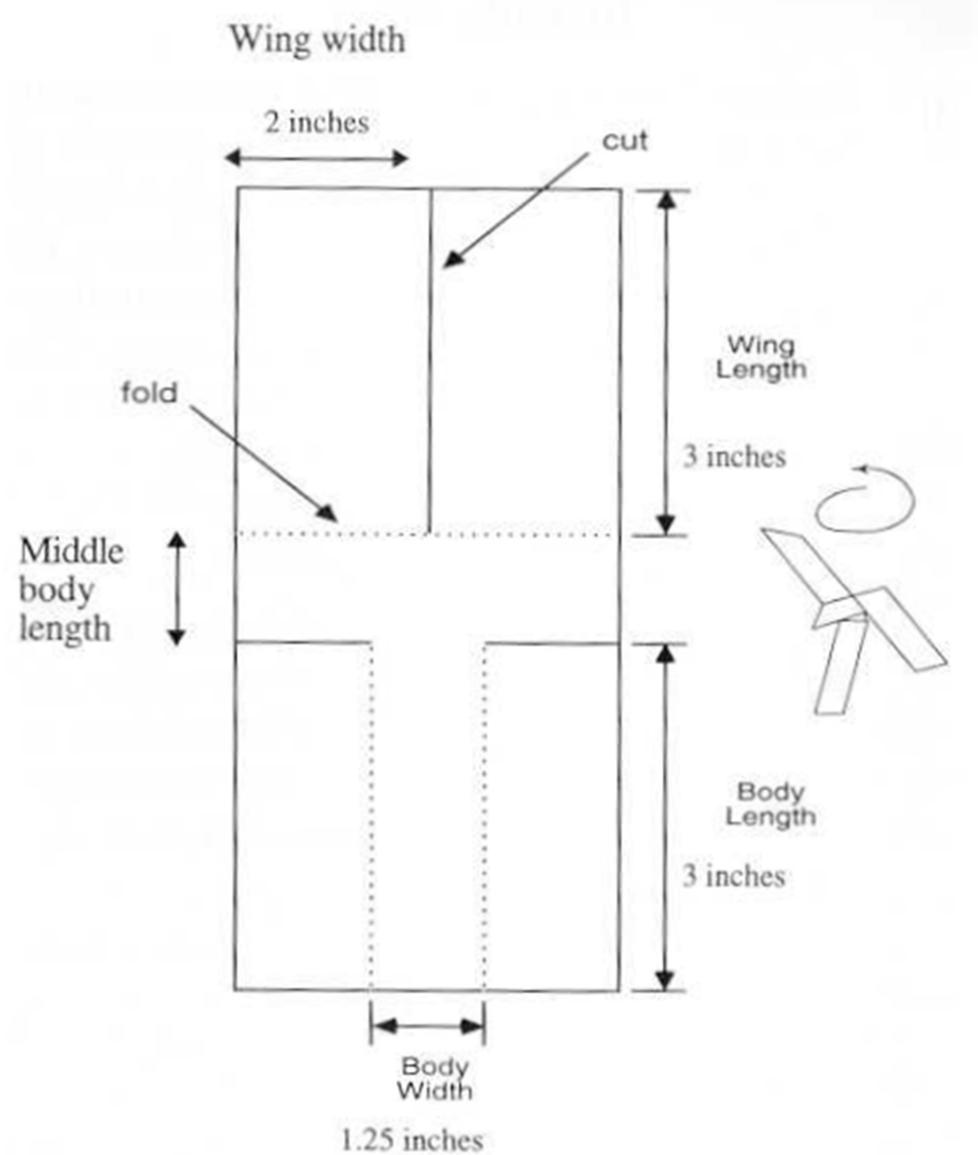
'Student' in 1908



R. A. Fisher (1890 – 1962)

George E. P. Box

Paper Helicopter



The Basic Principles of DOE

- **Randomization**
  - Running the trials in an experiment in random order
  - Notion of balancing out effects of “lurking” variables
- **Replication**
  - Sample size (improving precision of effect estimation, estimation of error or background noise)
  - Replication versus repeat measurements?
- **Blocking**
  - Dealing with nuisance factors

Strategy of Experimentation

- **"Best-guess" experiments**
  - Used a lot
  - More successful than you might suspect, but there are disadvantages…
- **One-factor-at-a-time (OFAT) experiments**
  - Sometimes associated with the "scientific" or "engineering" method
  - Devastated by interaction, also very inefficient
- **Statistically designed experiments**
  - Based on Fisher's factorial concept

Factorial Designs

- In a factorial experiment, **all possible combinations** of factor levels are tested
- The golf experiment:
  - Type of driver
  - Type of ball
  - Walking vs. riding
  - Type of beverage
  - Time of round
  - Weather
  - Type of golf spike
  - Etc, etc, etc…

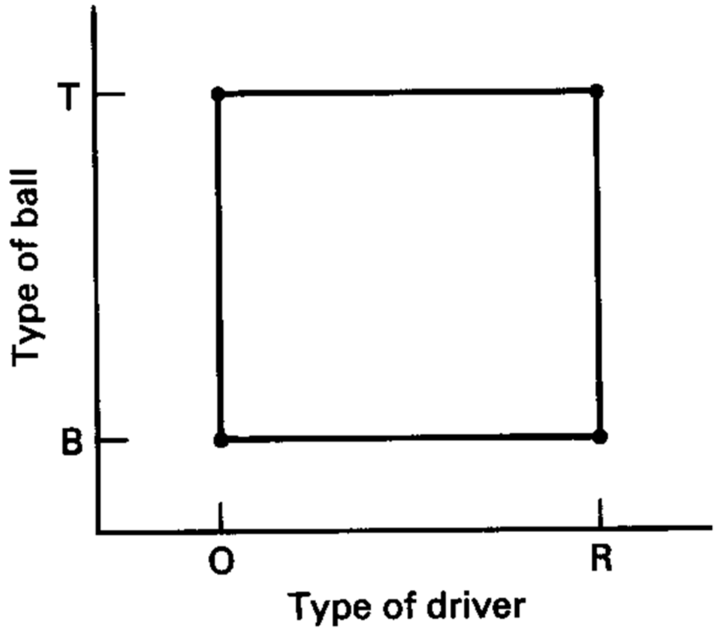


Figure 1-4 A two-factor factorial experiment involving type of driver and type of ball.

Factorial Design

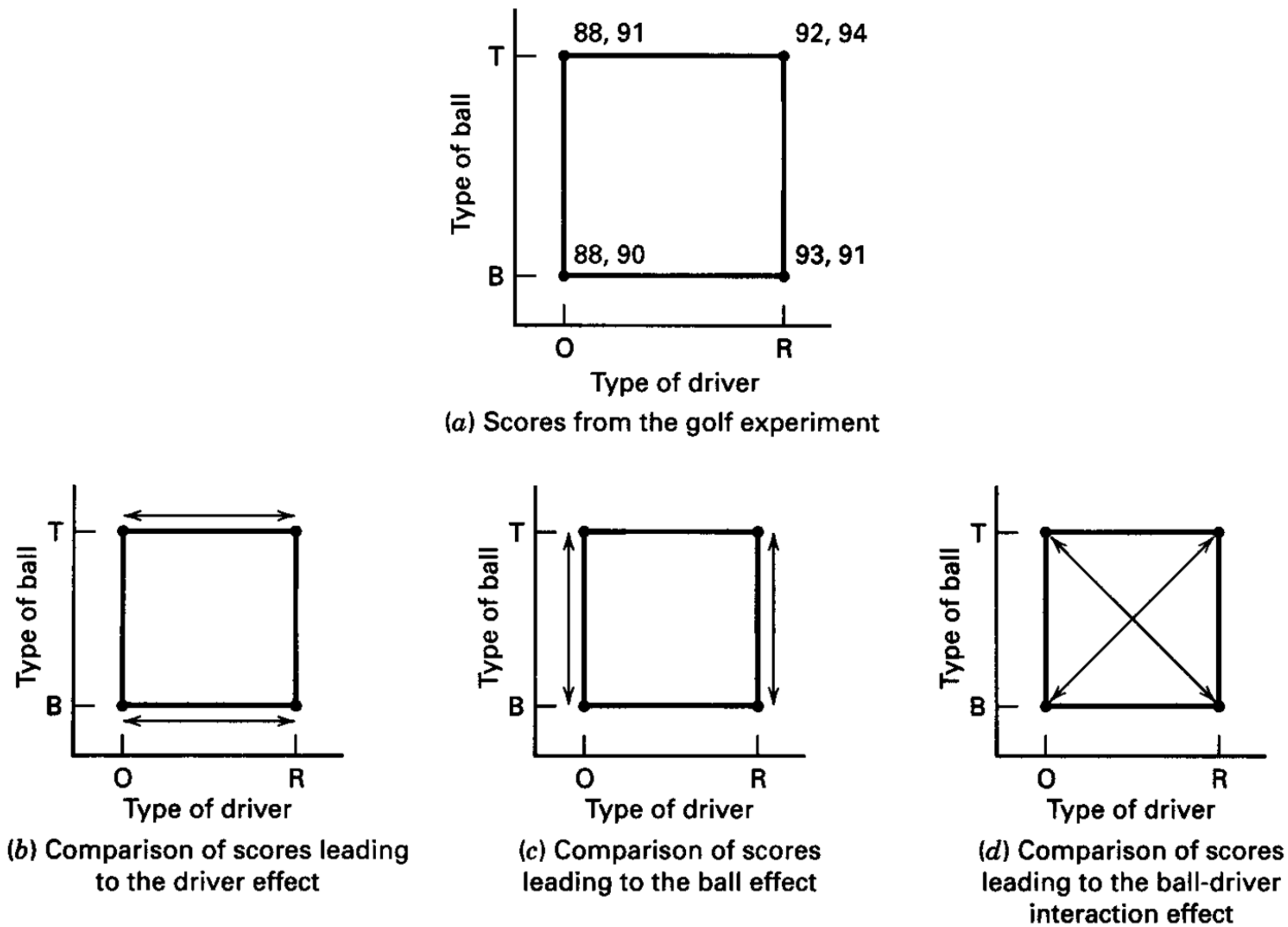


Figure 1-5 Scores from the golf experiment in Figure 1-4 and calculation of the factor effects.

Factorial Designs with Several Factors

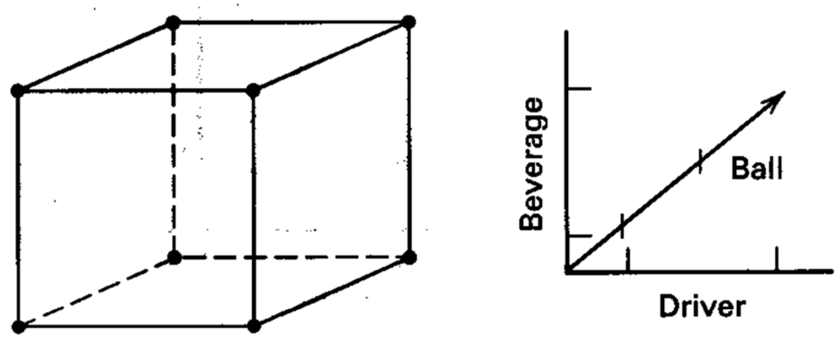


Figure 1-6 A three-factor factorial experiment involving type of driver, type of ball, and type of beverage.

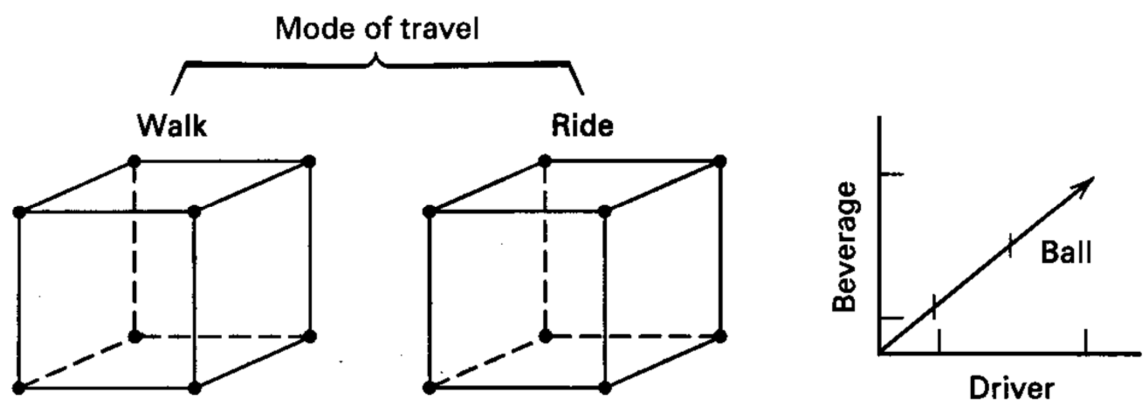


Figure 1-7 A four-factor factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

Factorial Designs with Several Factors: A Fractional Factorial

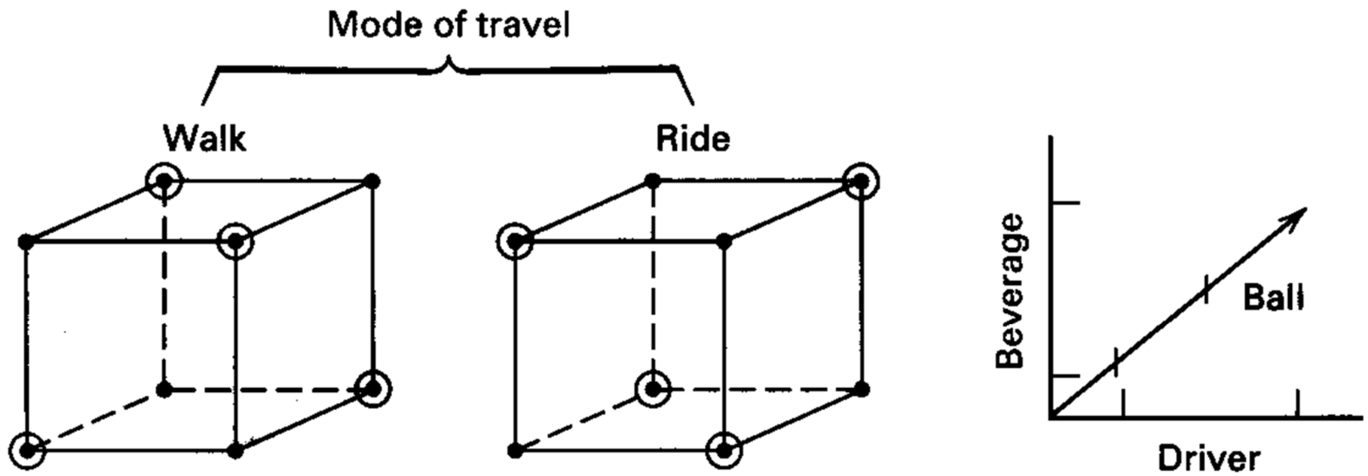


Figure 1-8 A four-factor fractional factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

Planning, Conducting & Analyzing an Experiment

1. Recognition of & statement of problem
   - Characterization, optimization, robustness?
2. Selection of the response variable (s)
   - Average, Variance, Multiples?
3. Choice of factors, levels, and ranges
   - All factors captured – design factors, held-constant factors, and allowed to vary factors.
   - Nuisance factors – controllable, uncontrollable or noise
4. Choice of design
   - Sample size, run order

Planning, Conducting & Analyzing an Experiment

5. Conducting the experiment
   - Monitoring for experimental error
6. Statistical analysis
   - Software packages, graphical methods, residual analysis and model adequacy checking
7. Drawing conclusions, recommendations
   - Follow-up runs, and confirmation testing
   - Iterative / sequential testing

Planning, Conducting & Analyzing an Experiment

- Get **statistical thinking** involved early
- Your **non-statistical** knowledge is crucial to success
- Pre-experimental planning (steps 1-3) vital
- Think and **experiment** sequentially
- See Coleman & Montgomery (1993) *Technometrics* paper