# Chapter 6
# Conducting Experiments and Studies

## Objectives

***After completing this chapter, you will be able to:***

- Upon successful completion of this chapter, you will be able to:
- Differentiate between a census and a survey or sample.
- Identify the important characteristics of an experiment.
- Distinguish between confounding and lurking variables.
- Use a random number generator to randomly assign experimental units to treatment groups.
- Identify experimental situations in which blocking is necessary or appropriate and create a blocking scheme for such experiments.

## Introduction

Statistics is a mathematical tool for quantitative analysis of data, and as such it serves as the means by which we extract useful information from data. In this chapter we are concerned with data that are generated via experimental measurement. Experimentation often generates multiple measurements of the same thing, i.e. replicate measurements, and these measurements are subject to error. Statistical analysis can be used to summarize those observations by estimating the average, which provides an estimate of the true mean. Another important statistical calculation for summarizing the observations is the estimate of the variance, which quantifies the uncertainty in the measured variable. Sometimes we have made measurements of one quantity and we want to use those measurements to infer values of a derived quantity. Statistical analysis can be used to propagate the measurement error through a mathematical model to estimate the error in the derived quantity. Sometimes we have measured two different things and we want to know whether there really is a difference between the two measured values. Analysis of variance (t-tests) can be used to estimate the probability that the underlying phenomena are truly different. Finally, we may have measured one variable under a variety of conditions with regard to a second variable. Regression analysis can be used to come up with a mathematical expression for the relationship between the two variables. These are but a few of the many applications of statistics for analysis of experimental data. This chapter presents a brief overview of these applications in the context of typical experimental measurements in the field of environmental engineering.

This chapter is necessarily brief in presentation. Students who seek a deeper understanding of these principles should study a textbook on statistical analysis of experimental data. The bibliography at the end of this chapter lists some useful textbooks, some of which are directly aimed at environmental engineers and scientists.

## Factors

Factors are explanatory variables to be studied in an investigation.

## Factor Levels

Factor levels are the "values" of that factor in an experiment. For example, in the study involving color of cars, the factor car color could have four levels: red, black, blue and grey. In a design involving vaccination, the treatment could have two levels: vaccine and placebo.

## Types Of Factors

- **Experimental factors:** levels of the factor are assigned at random to the experimental units.
- **Observational factors:** levels of the factor are characteristic of the experimental units and is not under the control of the investigators.
- There could be observational factors in an experimental study.

## Treatments

- In a single factor study, a treatment corresponds to a factor level; thus the number of treatments equals the number of different factor levels of that factor.
- In a multi-factor study, a treatment corresponds to a *combination of factor levels across different factors;* thus the number of all possible treatments is the prodcut of the number of factor levels of different factors.

Examples:

- In the study of effects of education on income, each education level is a treatment (high school, college, advanced degree, etc).
- In the study of effects of race and gender on income, each combination of race and gender is a treatment (Asian female; Hispanic male, etc).

## Choice Of Treatments

Choice of treatments depends on the choice of: (i) the factors (which are the important factors);

(ii) levels of each factor.

- For **qualitative factors** the levels are usually indicated by the nature of the factor.

A. For **quantitative factors** the choice of levels reflects the type of trend expected by the investigator.

- The **range of the levels** is also crucial. Usually prior knowledge is required for an effective choice of factors and treatments

## Experimental Units

- An experimental unit is the smallest unit of experimental material to which a treatment can be assigned.
- **Representativeness:** the experimental units should be representative of the population about which a conclusion is going to be drawn.
- Choosing a representative set of experimental units which fits teh purpose of your study is important.

## Sample Size And Replicates

Loosely speaking, sample size is the number of experimental units in the study.

- Sample size is usually determined by the trade-off between statistical considerations such as power of tests, precision of estimations, and the availability of resources such as money, time, man power, technology etc.
- In general, the larger teh sample size, the better it is for statistical inference; however, the costlier is the study.
- An important consideration in an experimental design is *how to assess power or precision as a function of the sample size*

## Replicates

For many designed studies, the sample size is an integer multiple of the total number of treatments. This integer is the number of times each treatment being repeated and one complete repitition of all treatments (under similar experimental conditions) is called a complete replicate of the experiment.

- *Example:* In a study of baking temperature on the volume of quick bread prepared from a package mix, four oven temperatures: low, medium, high and very high were tested by randomly assigning each temperature to 5 package mixes (all of the same brand). Thus the sample size is 20(= 4 ×× 5), the number of treatments is 4 (4 levels of temperatures) and there are 5 complete replicates of the experiment.

## Why Replicates?

When a treatment is repeated under the same experimental conditions, any difference in the response from prior responses for the same treatment is due to random errors. Thus replication provides us some information about random errors. If the variation in random errors is relatively small compared to the total variation in the response, we would have evidence for treatment effect.

## Randomization

- Randomization tends to average out between treatments whatever systematic effects may be present, apparent or hidden, so that the comparison between treatments measure only the pure treatment effect.
- Randomization is necessary not only for the assignment of treatments to experimental units, but also for other stages of the experiment, where systematic errors may be present.

In addition to randomizing the treatments, it is important to randomize the time slots also. This is because, the conditions of the growth chamber (such as humidity, temperature) might change over time. Therefore, growing all plants with brighter light treatment in the first 5 time slots and then growing all plants with darker light treatment in the last 5 time slots is not a good design.

## Blocking

In a **blocked experiment**, heterogenous experimental units (with known sources of heterogenity) are divided into homogenous subgroups, called blocks, and separate randomized experiments are conducted within each block.

- *Example:* in a study of Vitamin C on cold prevention, 1000 children were recruited. Half of them were randomly chosen and were given Vitamin C in their diet and the other half got placebos. At the end of the study, the number of colds contracted by each child was recorded. (This is an example of a *complete randomiz*ed design (CRD). )
- If we know (or have sufficient reason to believe) that gender may also influence the incidence of cold, then a more efficient way to conduct the study is through blocking on gender: 500 girls and 500 boys were recruited. Among the girls, 250 were randomly chosen and given Vitamin C and the other 250 were given placebo. Same is done for the 500 boys. (This is an example of a *randomized block design (RCBD).* )

- By blocking, one removes the source of variation due to potential **confounding factors** (here it is gender), and thus improves the efficiency of the inference of treatment effect (here it is Vitamin C)
- Randomization alone (as in CRD) does not assure that the same number of girls and boys will receive each treatment. Thus if there is a difference of cold incidence rate between genders, observed differences between treatment groups maybe observed even if there is indeed no treatment effect.

## Measurements Of Response Variables

The issue of **measurement bias** arises due to unrecognizable differences in the evaluation process.

*Example:* The knowledge of the treatment of a patient may influence the judgement of the doctor. The source of measurement bias can be reduced to concealing the treatment assignment to *both the subject and the evaluator*

**Video Links:**

***Conducting Experiments and Studies***

- https://www.coursera.org/lecture/social-science-study-chinese-society/7-2-experimental-designs-lovMZ
- https://courses.lumenlearning.com/mathforliberalarts corequisite/chapter/experiments/
- https://courses.lumenlearning.com/introstats1/chapter/experimental-design-and-ethics/

## References


- https://ssrmc.wm.edu/experimental-design-module/
- https://uca.edu/psychology/files/2013/08/Ch10-Experimental-Design_Statistical-Analysis-of-Data.pdf
- https://stats.libretexts.org/Bookshelves/Computing_and_Modeling/Supplemental_Modules_(Computing_and_Modeling)/Experimental_Design/Analysis_of_Variance/Components_of_an_experimental_study_design
- http://www.princeton.edu/~cap/AEESP_Statchap_Peters.pdf