Relevent Text Section:

See Chapter 26: Design of experiments, Randomization, and Sample Size Planning, sections 1 to 6.

Introduction

- Design of an experiment - a process of establishing a structure in order to compare treatments or groups in terms of a measurable (recordable) response.

- Data can be collected either in a natural setting (observing reading scores of second graders in private, religious, or public schools) or in a controlled setting (i.e. a laboratory - which could be a completely synthetic environment for the study).

- In a natural setting many factors can not be controlled (i.e. humidity, sunlight, rainfall, wind, etc. in an outdoor observational study)

- In a laboratory, many factors can be controlled at the expense of duplicating reality.

- One needs to balance the amount of control and the portrayal of reality when considering the usefulness of knowledge gained from an experiment.

Types of Studies

- Observational studies can take the form of polls, surveys, or epidemiological studies.

- In an observational study, we sample from populations where the factors under consideration are already present. Our goal is to make comparisons between the factors of interest and draw inference about the population based on the samples.

- In a controlled experiment, we randomly assign experimental units to factors. After the experiment is completed we examine the response using some unit of measure (i.e growth could be measured in weight, volume, height, etc.). We then make comparisons between the groups based on the recorded measure.

- Example: Suppose we are interested in the relationship between heart disease and the amount of fat consumed in one’s diet. We could make inference about this relationship by using either an observational study or a controlled experiment. The study for each would be carried out as follows:

  1. Observational study - Draw a sample from the heart disease population. Draw another sample from the heart disease-free population. Compare the fat content of the diets between the two groups.

  2. Experimental study - Randomly assign volunteers to diets containing various levels of fat content. Compare a measure of heart disease between the diets. Do you see any problems with this method for this research question?!
Our focus will be on designed experiments. We can exert control over factors using one of two methods.

1. Method 1: Subjects are randomly assigned to treatments. Here the researcher has complete control over the assignments of the subjects to the treatments. Example - Randomly assign homogeneous soy bean seedlings to fields that have been treated with different levels of nitrogen.

2. Method 2: Subjects are randomly selected from populations of interest. Here the researcher does not have control over the assignment of the experimental units to the treatments under consideration. The researcher can control the sampling from the populations. Example - Randomly select 50 dogs from an urban and a rural animal shelter. Using a measure of heart worm infestation, determine the prevalence of heart worms in rural Vs urban settings. Note: Here, we did not assign dogs to urban or rural environments.

A researcher must follow a systematic plan established prior to the experiment. Among the items that should be contained within the plan are 1.) research objectives, 2.) factors, 3.) extraneous factors, 4.) the response (yield, growth, survival, etc.), 5.) method of randomization, 6.) measurement procedures, 7.) number of experimental units.

**Designed Experiments: Terminology**

We will begin with an example to assist in defining some basic terminology of experimental design.

Example - The effects of water temperature and salinity levels in the weight gain of commercially raised shrimp.

- Water temperatures: 25° 30° 35°.
- Salinity levels: 10% 20% 30% 40%.
- Procedure: Shrimp will be raised in 24 containers over 6 weeks at which time the shrimp will be harvested and weighed.
- Extraneous factors to be controlled: density, shrimp variety, size of shrimp, feed type.
- Randomization: Shrimp containers are assigned to a water temperature / salinity combination.

- Factors - variables controlled by the researcher. In the example above, the two factors are water temperature and salinity level.

- Measurements/observations - a variable not controlled by the researcher. These are also called response variables and are recorded. Shrimp weight is the measurement (or response) in the example above.

- Treatments - These are the conditions created by the factors. In the example above, we have a factorial treatment design since every level of water temperature will be combined with each level of salinity resulting in \(3 \times 4 = 12\) treatments. Note that
we have 24 containers, thus we will assign two containers to each temperature-salinity combination.

Example: Suppose we are interested in increasing the per acre yield of soy beans. After a review of the current literature on soy beans and experience the conjecture is that five factors contribute to soy bean yield. The five factors are:

1. Variety - You decide to examine five different varieties.
2. Planting density - Examine three different planting densities.
3. Fertilization - Examine four different levels of fertilization.
4. Location - You try six different locations around Texas.
5. Irrigation - Examine three rates of irrigation.

How many treatment combinations are there in the experiment? (5)(3)(4)(6)(3) = 1080 combinations. This is a very large experiment that would be very expensive in financial and labor resources.

Terminology (cont’d)

- Fractional factorial experiment - Here we only consider a fraction of the possible treatments. The preceding soybean experiment is a prime candidate for this type.

- Control treatment - This is a special type of treatment often called a benchmark. Control treatments can be used in the following three ways.
  1. The control consisting of no treatment may be used to demonstrate that conditions exist that mask the effectiveness of the remaining treatments. Example: Nitrogen treatment levels Vs Existing soil fertility.
  2. Use the control as the status quo. New treatments may consist of new methodologies. Example: Old drug Vs New drug.
  3. Use the control as a placebo. In this case, the response may be sensitive to manipulation of the subject during the experiment. Example: Sugar pill Vs New headache medicine.

- Experimental unit - This is the actual entity to which the treatment is randomly assigned (see previous Method 1). It could also be the subject that is randomly selected from one of the treatment populations (see previous Method 2). In the previous shrimp study, the 24 experimental units are the 24 containers.

- Measurement unit - This is the actual entity on which a measure is taken (i.e. weight, height, survival, etc). The experimental unit and measurement unit may or may not be the same! Note: Shrimp example, the measurement unit and experimental unit are the same. Had we decided to weigh each shrimp within a container then the individual shrimp would be the measurement unit and the container would still be the experimental unit.
• Replication - A random assignment of a treatment to an experimental unit 
results in one replication. We will have several replications per treatment. These 
replications yield (under randomization) independent observations.

• Experimental Error - This represents the variation in the responses within the same 
treatment. Why is experimental error not zero? Below are a few reasons:

  1. Natural differences among experimental units.
  2. Variation in measurement devices.
  3. Variation in setting treatment conditions.
  4. Treatment affects on extraneous factors.

• Variance of experimental error - later, we will assume that experimental error is an 
independent and identically distributed random variable following some distribution. 
This distribution will have a mean and a variance. We will estimate the variance of 
this random variable which will depend on how the treatments have been assigned (the 
experimental design) and replication.

Example: Identifying sources of experimental error. Suppose we are testing various dose 
levels (the treatments) of a new drug on laboratory rats. We randomly assign a single dose 
level to a rat, administer the drug, and sample the rat’s blood in two hours. Sources of 
experimental error in this scenario are as follows:

  1. Natural differences - the physiology of the rats are not the same! Note: Even if the 
rats were cloned, their physiology would not be the same even though their genetic 
make-up would be so.

  2. Variation in measurement devices - this includes the technician collecting the data as 
well as the equipment and conditions of the laboratory. A note to scientists: being 
consistent and precise in your lab techniques is critical as you can effect the outcome 
of the results in many ways!

  3. Variation in treatment conditions - it may be the case that different batches of the 
drug were administered. In this case, even though we may have controlled the dose 
level it is still possible that variation exists among batches.

  4. Extraneous factors - for this example may include the living conditions of the rats 
(food, water, housing, etc.) and external stimulation (noise, temperature, humidity, 
etc).

Controlling Experimental Error

When the variance of experimental error is large, inference is compromised. As a researcher, 
we want to control as many sources of experimental error as possible (within obvious financial 
and time constraints). Following are sources of experimental error and associated controls.
1. Experimental procedures

- Procedures involve personnel, equipment, and supplies.
- Personnel (this could be you!) should be trained and/or hone their lab technical skills.
- Improper techniques may inflate variability in the data (i.e. gel preparation, etc.).
- Lack of uniformity in techniques throughout the study period.
- Uniform lab conditions throughout the study period.

2. Experimental and measurement units

- This is relative to the population the researcher wishes to make inference on.
- Overly uniform populations will yield more precise measurements at the expense of restricted inference.
- Lack of uniformity may make the results more generalizeable, but can inflate experimental error.
- Balance is key!

- Example: Marketing firm wants to test the attention span of children on different products. The firm selects four different kinds of products (sports equipment, healthy snacks, shoes, and video games). 100 children are selected from a fourth grade class from a NYC public school. 25 students are randomly selected for each of the four types of commercials. The attention spans were then recorded. What potential problems exist with this selection procedure?

- Solution: Clearly homogeneity of the experimental units was achieved by restricting the population to the same grade level and school system. The results, however, may be restricted to inference about fourth graders in a large city public school. The experiment can be improved by selecting other grades levels and additionally, from smaller schools.

3. Blocking

- Blocking can be effective when there are large differences in the experimental units.
- Experimental units are placed in groups based on their similarity with respect to characteristics that may affect the response.
- Thus, blocking, enables one to separate or remove variability associated with the blocking characteristics.
- Examples of blocking criteria are as follows:
  (a) Physical characteristics - age, weight, sex, healthy, education, etc.
  (b) Related units - litters or twins
(c) Spatial location - plots of land (dry, moist, shade, fertility levels) or laboratory position
(d) Time - Day of the week
(e) People - those that conduct the experiment can be used as blocks (i.e. a garment inspector)

- We will say more about blocking when we look at specific experimental designs.

4. Covariates

- A covariate is a variable that is related to the response. It must be measureable and can not be affected by the treatment.
- A covariate is usually measured prior to the study. If measured during the study, it should not be influenced by the treatment.
- Do not confuse this with blocking. Recall that a block is a characteristic of the experimental unit.
- Example: Suppose we are testing a new diet formulation in dog food with the goal of trimming down overweight dogs.
  (a) Blocking would take place if we grouped the dogs into, say, three weight groups.
  (b) A covariate could be used instead by using the actual pre-diet weight of the dog in the model.
  (c) Choosing to weigh the dog during the study would be incorrect as a dog’s weight is influenced by diet.
- We will say more about this when we study Analysis of Covariance (ANCOVA)