STATISTICS

FOR ENGINEERING AND THE SCIENCES

FIFTH EDITION

WILLIAM MENDENHALL TERRY SINCICH

FIFTH EDITION

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STATISTICS

for Engineering and the Sciences

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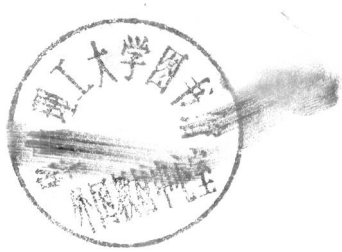

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Preface

Overview

This text is designed for a two-semester introductory course in statistics for students majoring in engineering or any of the physical sciences. Inevitably, once these students graduate and are employed, they will be involved in the collection and analysis of data and will be required to think critically about the results. Consequently, they need to acquire knowledge of the basic concepts of data description and statistical inference and familiarity with statistical methods they are required to use on the job.

Pedagogy

Chapters 1–6 identify the objectives of statistics, explain how we can describe data sets, and present the basic concepts of probability. Chapters 7 and 8 introduce the two methods for making inferences about population parameters: estimation and testing hypotheses. These notions are extended in the remaining chapters to cover other topics that are useful in analyzing engineering and scientific data, including the analysis of categorical data (Chapter 9), regression analysis and model building (Chapters 10–12), the analysis of variance for designed experiments (Chapters 13–14), nonparametric statistics (Chapter 15), statistical quality control (Chapter 16), and product and system reliability (Chapter 17).

The assumed mathematical background is a two-semester sequence in calculus—that is, the course could be taught to students of average mathematical talent and with a basic understanding of the principles of differential and integral calculus. Presentation requires the ability to perform one-variable differentiation and integration, but examples involving topics from multivariable calculus are designated as optional. Thus, the theoretical concepts are sketched and presented in a one-variable context, but it is easy for the instructor to delve deeper into the theoretical and mathematical aspects of statistics using the optional topics, examples, and exercises.

Features

Specific features of the text are as follows:

1. **Blend of theory and applications.** The basic theoretical concepts of mathematical statistics are integrated with a two-semester presentation of statistical methodology. Thus, the instructor has the option of presenting a course with either of two characteristics—a course stressing basic concepts and applied statistics, or a course that, while still tilted toward application, presents a modes introduction to the theory underlying statistical inference.
2. **Statistical software applications with tutorials.** The instructor and student have the option of using statistical software to perform the statistical calculations. Printouts from three popular statistical software packages—SAS, SPSS, and MINITAB—as well as Microsoft Excel output are fully integrated into the text. Tutorials with menu screens and dialog boxes are provided in Appendices C, D, and E. These tutorials are designed for the novice user; no prior experience with the software in needed.

3. **Blended coverage of topics and applications.** To meet the diverse needs of future engineers and scientists, the text provides coverage of a wide range of data analysis topics. The material on multiple regression and model building (Chapters 11–12), principles of experimental design (Chapter 13), quality control (Chapter 16), and reliability (Chapter 17) sets the text apart from the typical introductory statistics text. Although the material often refers to theoretical concepts, the presentation is oriented toward applications.
4. **Numerous real data-based exercises.** The text contains a large number of applied exercises designed to motivate students and suggest future uses of the methodology. Nearly every exercise is based on data or experimental results extracted from professional journals or obtained from organizations in the engineering and physical sciences. Exercises are located at the ends of key sections and at the ends of chapters.
5. **"Statistics in Action" case studies.** The Fifth Edition of the text now includes a contemporary scientific study ("Statistics in Action") and the accompanying data and analysis at the end of each chapter. Our goal is to show students the importance of applying sound statistical techniques in order to evaluate the findings and to think through the statistical issues involved.
6. **Data sets provided online.** All of the data sets associated with examples, exercises, and cases are provided online at www.prenhall.com (search for this textbook). Each data set is marked with a CD icon and file name in the text. The data files are saved in five different formats: MINITAB, SAS, SPSS, Excel, and ASCII (for easy importing into other statistical software packages). By analyzing these data using statistical software, calculations are minimized, allowing students to concentrate on the interpretation of the results.

New to the Fifth Edition

Although the scope and coverage remain the same, the Fifth Edition of the text contains several substantial changes, additions, and enhancements:

1. **"Statistics in Action" cases at the end of each chapter.** As mentioned above, the text now includes a discussion of an actual, recent scientific study at the end of each chapter. The data and analysis are discussed in detail, demonstrating how the statistical methods of the chapter are used to answer relevant questions in the field.
2. **Updated statistical software printouts.** Throughout the text we have greatly increased the number of printouts, and now include the newest versions of SPSS and EXCEL output as well as updated SAS and MINITAB printouts. A printout accompanies every statistical technique presented, allowing the instructor to emphasize interpretations of the statistical results rather than the calculations required to obtain the results.
3. **End-of-chapter summary material.** At the end of each chapter, we provide a summary of the topics presented via a Quick Review (key words and key formulas), Language Lab (a listing of key symbols and pronunciation guide), and Chapter Summary Notes. These features help the student summarize and reinforce the important points from the chapter and are useful study tools.
4. **More exercises with real data** Many new "real-life" scientific exercises have been added throughout the text. All of these are extracted from news articles, scientific magazines, and professional journals.
5. **Chapter 1: Statistics and critical thinking.** A new section on the role of statistics in the assessment of the credibility and value of the inferences made from data—i.e., critical thinking (Section 1.4)—has been added.

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6. **Chapter 2: Distorting the truth with descriptive statistics.** Several examples on how graphs and numerical descriptive measures can be used to give a distorted view of the data, and how to recognize when this occurs, are now included in a new section (Section 2.8).
7. **Chapters 4–6: Standard mathematical notation for a random variable.** Throughout the chapters on random variables, we now use the standard mathematical notation for representing a random variable. Uppercase letters are used to represent the random variable, and lowcase letters represent the values that the random variable can assume.
8. **Chapter 6: Monte Carlo simulation.** We emphasize the use of Monte Carlo simulation for approximating a sampling distribution through examples in Section 6.8.
9. **Chapters 7 and 8: Bootstrapping and Bayesian methods.** New optional sections now present two alternative estimation methods (Section 7.12) and hypothesis-testing methods (Section 8.13)—bootstrapping and Bayesian methods.
10. **Chapter 9: Exact tests for a contingency table.** A new optional section (Section 9.6) presents Fisher's exact test for independence in a 2×2 contingency table.
11. **Chapter 11: Multiple regression models.** Examples of several different multiple regression models are given in separate sections in Chapter 11–a first-order model (Section 11.7), an interaction model (Section 11.8), and a second-order model (Section 11.9).
12. **Chapter 12: External model validation.** A new optional section (Section 12.9) on validating a multiple regression model externally has been added to the model-building chapter, Chapter 12. Cross-validation and jackknifing methods are discussed.
13. **Chapters 13 and 14: Experimental design and ANOVA.** The previous material on analysis of variance is now presented in two chapters: "Principles of Experimental Design" (Chapter 13) and "ANOVA for Designed Experiments" (Chapter 14).
14. **Chapter 16: Capability analysis.** The chapter on statistical process and quality control now includes a new optional section (Section 16.9) on the importance of a capability analysis.

Numerous, less obvious changes in details have been made throughout the text in response to suggestions by current users and reviewers of the text.

Supplements

The text is also accompanied by the following supplementary material:

1. **Student's Solutions Manual** (by Mark Dummeldinger) (ISBN: 0-13-187708-9). The manual contains the full solutions for all the odd-numbered exercises contained in the text.
2. **Instructor's Solutions Manual** (by Mark Dummeldinger) (ISBN: 0-13-187707-0). The manual contains the full solutions to all the even-numbered exercises contained in the text.

Acknowledgments

This book reflects the efforts of a great many people over a number of years. First, we would like to thank the following professors, whose reviews and comments on this and prior editions have contributed to the Fifth Edition:

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CHAPTER 1

Introduction

OBJECTIVE

To identify the role of statistics in the analysis of data from engineering and the sciences

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1.1 Statistics: The Science of Data

1.2 Fundamental Elements of Statistics

1.3 Types of Data

1.4 The Role of Statistics in Critical Thinking

1.5 A Guide to Statistical Methods Presented in This Text

- *STATISTICS IN ACTION*
  Contamination of Fish in the Tennessee River: Collecting the Data

1.1 Statistics: The Science of Data

According to *The Random House College Dictionary*, statistics is "the science that deals with the collection, classification, analysis, and interpretation of numerical facts or data." In short, **statistics** is the **science of data.**

Definition 1.1

Statistics is the science of data. This involves collecting, classifying, summarizing, organizing, analyzing, and interpreting data.

The science of statistics is commonly applied to two types of problems:

1. Summarizing, describing, and exploring data
2. Using sample data to infer the nature of the data set from which the sample was selected

As an illustration of the descriptive applications of statistics, consider the United States census, which involves the collection of a data set that purports to characterize the socioeconomic characteristics of the approximately 295 million people living in the United States. Managing this enormous mass of data is a problem for the computer software engineer, and describing the data utilizes the methods of statistics. Similarly, an environmental engineer uses statistics to describe the data set consisting of the daily emissions of sulfur oxides of an industrial plant recorded for 365 days last year. The branch of statistics devoted to these applications is called **descriptive statistics.**

Definition 1.2

The branch of statistics devoted to the organization, summarization, and description of data sets is called **descriptive statistics.**

Sometimes the phenomenon of interest is characterized by a data set that is either physically unobtainable or too costly or time-consuming to obtain. In such situations, we obtain a subset of the data—called a *sample*—and use the sample information to infer its nature. To illustrate, suppose the phenomenon of interest is the drinking-water quality on an inhabited, but remote, Pacific island. You might expect water quality to depend on such factors as temperature of the water, the level of the most recent rainfall, etc. In fact, if you were to measure the water quality repeatedly within the same hour at the same location, the quality measurements would vary, even for the same water temperature. Thus, the phenomenon "drinking-water quality" is characterized by a large data set that consists of many (actually, an infinite number of) water quality measurements—a data set that exists only conceptually. To determine the nature of this data set, we *sample* it—i.e., we record quality for n water specimens collected at specified times and locations, and then use this sample of n quality measurements to infer the nature of the large conceptual data set of interest. The branch of statistics used to solve this problem is called **inferential statistics**.

Definition 1.3

The branch of statistics concerned with using sample data to make an inference about a large set of data is called **inferential statistics.**

1.2 Fundamental Elements of Statistics

In statistical terminology, the data set that we want to describe, the one that characterizes a phenomenon of interest to us, is called a **population.** Then, we can define a **sample** as a subset of data selected from a population. Sometimes, the words *population* and *sample* are used to represent the objects upon which the measurements

are taken (i.e., the *experimental units*). In a particular study, the meaning attached to these terms will be clear by the context in which they are used.

Definition 1.4

A statistical **population** is a data set (usually large, sometimes conceptual) that is our target of interest.

Definition 1.5

A **sample** is a subset of data selected from the target population.

Definition 1.6

The object (e.g., person, thing, transaction, specimen, or event) upon which measurements are collected is called the **experimental unit.** (*Note:* A population consists of data collected on many experimental units.)

In studying populations and samples, we focus on one or more characteristics or properties of the experimental units in the population. The science of statistics refers to these characteristics as **variables.** For example, in the drinking-water quality study, two variables of interest to engineers are the chlorine-residual (measured in parts per million) and the number of fecal coliforms in a 100-milliliter water specimen.

Definition 1.7

A **variable** is a characteristic or property of an individual experimental unit.

Example 1.1

Engineers with the University of Kentucky Transportation Research Program have collected data on accidents occurring at intersections in Lexington, Kentucky. One of the goals of the study was to estimate the rate at which left-turn accidents occur at intersections without left-turn-only lanes. This estimate will be used to develop numerical warrants (or guidelines) for the installation of left-turn lanes at all major Lexington intersections. The engineers collected data at each of 50 intersections without left-turn-only lanes over a 1-year period. At each intersection, they monitored traffic and recorded the total number of cars turning left that were involved in an accident.

a. Identify the variable and experimental unit for this study.
b. Describe the target population and the sample.
c. What inference do the transportation engineers want to make?

Solution

a. Since the engineers collected data at each of 50 intersections, the experimental unit is an intersection without a left-turn-only lane. The variable measured is the total number of cars turning left that were involved in an accident.
b. The goal of the study is to develop guidelines for the installation of left-turn lanes at all major Lexington intersections; consequently, the target population consists of all major intersections in the city. The sample consists of the subset of 25 intersections monitored by the engineers.
c. The engineers will use the sample data to estimate the rate at which left-turn accidents occur at all major Lexington intersections. (We learn, in Chapter 7, that this estimate is the number of left-turn accidents in the sample divided by the total number of cars making left turns in the sample.)

The preceding definitions and example identify four of the five elements of an inferential statistical problem: a population, one or more variables of interest, a sample, and an inference. The fifth element pertains to knowing how good the inference is—that is, the **reliability** of the inference. The measure of reliability that accompanies an inference separates the science of statistics from the art of fortune-telling. A palm

reader, like a statistician, may examine a sample (your hand) and make inferences about the population (your future life). However, unlike statistical inferences, the palm reader's inferences include no measure of how likely the inference is to be true.

To illustrate, consider the transportation engineers' estimate of the left-turn accident rate at Lexington, Kentucky, intersections in Example 1.1. The engineers are interested in the *error of estimation* (i.e., the difference between the sample accident rate and the accident rate for the target population). Using statistical methods, we can determine a *bound on the estimation error*. This bound is simply a number (e.g., 10%) that our estimation error is not likely to exceed. In later chapters, we learn that this bound is used to help measure our "confidence" in the inference. The reliability of statistical inferences is discussed throughout this text. For now, simply realize that an inference is incomplete without a measure of reliability.

Definition 1.8

A **measure of reliability** is a statement (usually quantified) about the degree of uncertainty associated with a statistical inference.

A summary of the elements of both descriptive and inferential statistical problems is given in the following boxes.

Four Elements of Descriptive Statistical Problems

1. The population or sample of interest
2. One or more variables (characteristics of the population or sample units) that are to be investigated
3. Tables, graphs, or numerical summary tools
4. Identification of patterns in the data

Five Elements of Inferential Statistical Problems

1. The population of interest
2. One or more variables (characteristics of the experimental units) that are to be investigated
3. The sample of experimental units
4. The inference about the population based on information contained in the sample
5. A measure of reliability for the inference

Applied Exercises

1.1 *Steel anticorrosion study.* Researchers at the Department of Materials Science and Engineering, National Technical University (Athens, Greece), examined the anticorrosive behavior of different epoxy coatings on steel. (*Pigment & Resin Technology*, Vol. 32, 2003.) Flat panels cut from steel sheets were coated with one of four different types of epoxy (S1, S2, S3, and S4). After exposing the panels to water for one day, the corrosion rate (nanoamperes per square centimeter) was determined for each panel.

a. What are the experimental units for the study?
b. Suppose you are interested in describing only the corrosion rates of steel panels coated with epoxy type S1. Define the target population and relevant sample.

SWREUSE

1.2 *Success/failure of software reuse.* The PROMISE Software Engineering Repository, hosted by the University of Ottawa, is a collection of publicly available data sets to serve researchers in building prediction software models. A PROMISE data set on software reuse, saved in the **SWREUSE** file, provides information on the success or failure of reusing previously developed software for each project in a sample of 24 new software development projects. (Data source: *IEEE Transactions on Software Engineering*, Vol. 28, 2002.) Of the 24 projects, 9 were judged failures and 15 were successfully implemented.

a. Identify the experimental units for this study.
b. Describe the population from which the sample is selected.
c. Use the sample information to make an inference about the population.

1.3 *Orchard contamination from insecticides.* Pesticides applied to an extensively grown crop can result in inadvertent

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