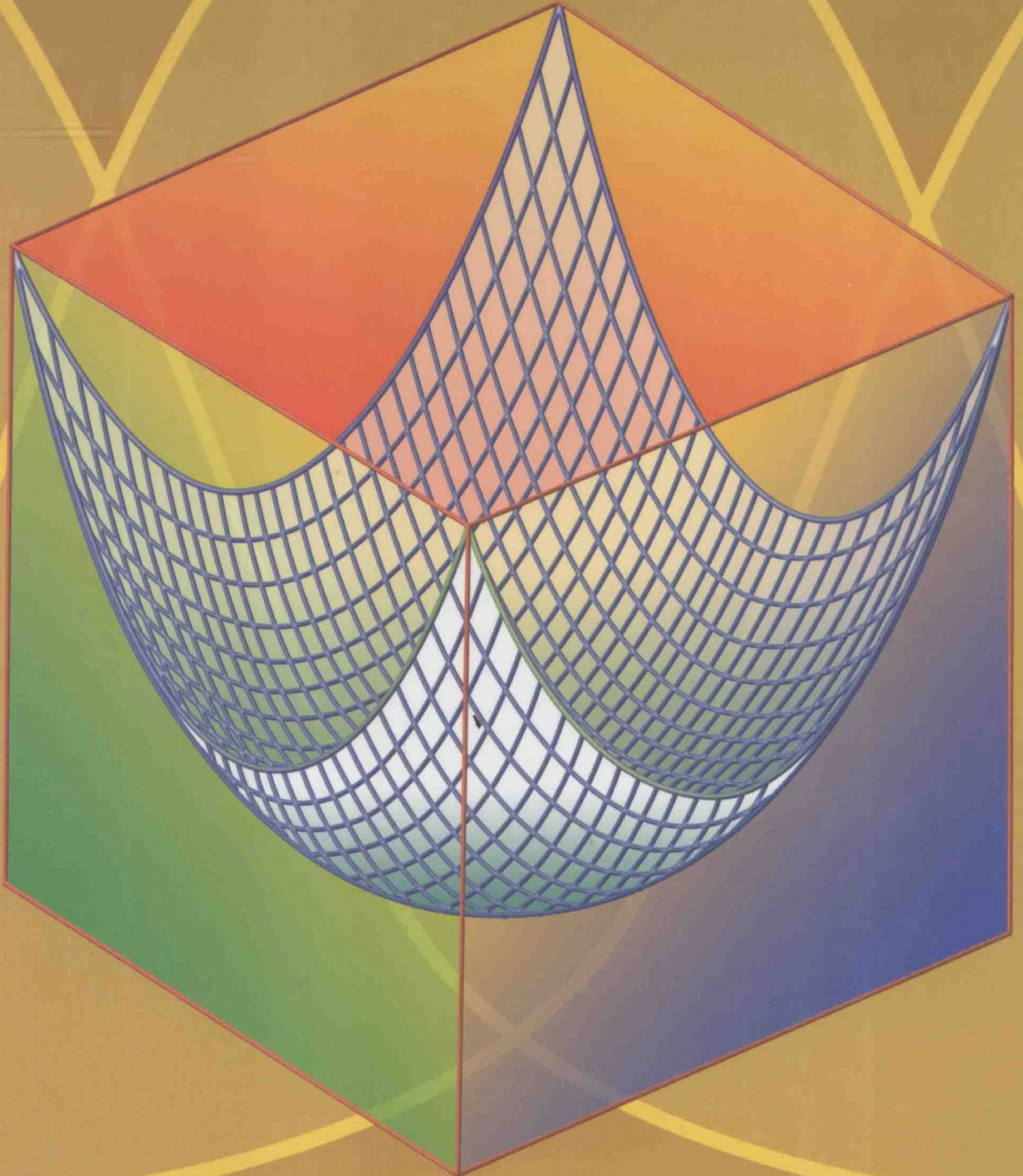


FOURTH EDITION

ENGINEERING STATISTICS



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HUBELE

Engineering Statistics

Fourth Edition


Douglas C. Montgomery
George C. Runger
Norma Faris Hubele
Arizona State University



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Library of Congress Cataloging-in-Publication Data

Montgomery, Douglas C.

Engineering statistics/Douglas C. Montgomery, George C. Runger, Norma Faris Hubele.—4th ed.

p. cm.

Includes index.

ISBN-13: 978-0-471-73557-1 (cloth)

1. Statistics. 2. Probabilities. I. Runger, George C. II. Hubele, Norma Faris, 1953- III. Title.

QA276.12.M6453 2006b

519.5'024'62—dc22

2006030759

Printed in the United States of America

10 9 8 7 6 5 4 3

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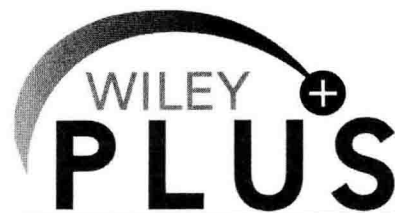
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3-9 POISSON DISTRIBUTION

We introduce the Poisson distribution with an example.

Example 3-30

Consider the transmission of n bits over a digital communication channel. Let the random variable X equal the number of bits in error. When the probability that a bit is in error is constant and the transmissions are independent, X has a binomial distribution. Let p denote the probability that a bit is in error. Let $\lambda = pn$. Then, $E(X) = pn = \lambda$ and

$$P(X = x) = \binom{n}{x} p^x (1-p)^{n-x} = \binom{n}{x} \left(\frac{\lambda}{n}\right)^x \left(1 - \frac{\lambda}{n}\right)^{n-x}$$

Now, suppose that the number of bits transmitted increases and the probability of an error decreases exactly enough that pn remains equal to a

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A batch of 590 machined parts contains 10 that do not conform to customer requirements. Parts are selected successively, without replacement, until a nonconforming part is obtained. The random variable is the number of parts selected. Determine the range (possible values) of the random variable.

☐ {0,1,2,...,590}
☐ {1,2,...,591}
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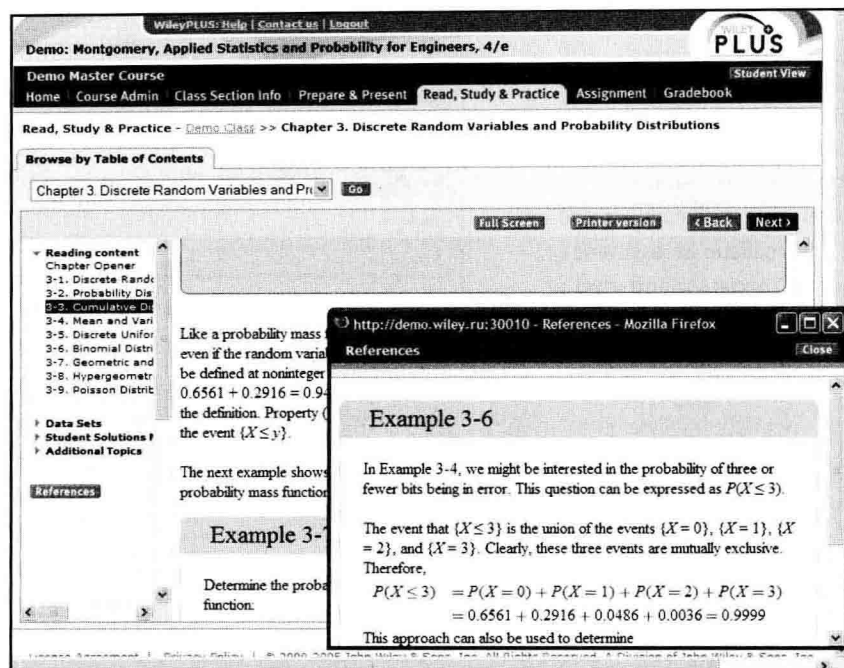
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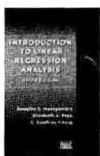
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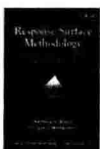
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About the Authors



Douglas C. Montgomery, Regents' Professor of Industrial Engineering and Statistics at Arizona State University, received his B.S., M.S., and Ph.D. degrees in engineering from Virginia Polytechnic Institute. He has been a faculty member of the School of Industrial and Systems Engineering at the Georgia Institute of Technology and a professor of mechanical engineering and director of the Program in Industrial Engineering at the University of Washington, where he held the John M. Fluke Distinguished Chair of Manufacturing Engineering. The recipient of numerous awards including the Stewart Medal of the American Society for Quality, two Brumbaugh Awards, the William G. Hunter Award, and two Shewell Awards from the ASQ. He is the editor of *Quality and Reliability Engineering International* and a former editor of the *Journal of Quality Technology*.



George C. Runger, Ph.D., is a Professor in the department of Industrial Engineering at Arizona State University. His research is on data mining, real-time monitoring and control, and other data-analysis methods with a focus on large, complex, multivariate data streams. His work is funded by grants from the National Science Foundation and corporations. In addition to academic work, he was a senior engineer at IBM. He holds degrees in industrial engineering and statistics.



Norma Faris Hubele, Professor of Engineering and Statistics at Arizona State University, and Director of Strategic Initiatives for the Ira A. Fulton School of Engineering, holds degrees in mathematics, operations research, statistics and computer and systems engineering. She is co-owner and serves as vice-president for Quality Control and Statistical Analysis at the Phoenix-based Refrac System. She is on the editorial board of the *Journal of Quality Technology* and *Quality Technology & Quantity Management*, as a founding member. Her specializations include capability analysis, transportation safety and statistics in litigation.

Preface

INTENDED AUDIENCE

Engineers play a significant role in the modern world. They are responsible for the design and development of most of the products that our society uses, as well as the manufacturing processes that make these products. Engineers are also involved in many aspects of the management of both industrial enterprises and business and service organizations. Fundamental training in engineering develops skills in problem formulation, analysis, and solution that are valuable in a wide range of settings.

Solving many types of engineering problems requires an appreciation of variability and some understanding of how to use both descriptive and analytical tools in dealing with variability. Statistics is the branch of applied mathematics that is concerned with variability and its impact on decision making. This is an introductory textbook for a first course in engineering statistics. Although many of the topics we present are fundamental to the use of statistics in other disciplines, we have elected to focus on meeting the needs of engineering students by allowing them to concentrate on the applications of statistics to their disciplines. Consequently, our examples and exercises are engineering based, and in almost all cases, we have used a real problem setting or the data either from a published source or from our own consulting experience.

Engineers in all disciplines should take at least one course in statistics. Indeed, the Accreditation Board on Engineering and Technology is requiring that engineers learn about statistics and how to use statistical methodology effectively as part of their formal undergraduate training. Because of other program requirements, most engineering students will take only one statistics course. This book has been designed to serve as a text for the one-term statistics course for all engineering students.

The Fourth edition has been extensively revised and includes some new examples and many new problems. In this revision we have focused on rewriting topics that our own teaching experience or feedback from others indicated that students found difficult.

ORGANIZATION OF THE BOOK

The book is based on a more comprehensive text (Montgomery, D. C., and Runger, G. C., *Applied Statistics and Probability for Engineers*, Fourth Edition, Hoboken, NJ: John Wiley & Sons, 2006) that has been used by instructors in a one- or two-semester course. We have taken the key topics for a one-semester course from that book as the basis of this text. As a result of this condensation and revision, this book has a modest mathematical level. Engineering students who have completed one semester of calculus should have no difficulty reading nearly all of the text. Our intent is to give the student an understanding of statistical methodology and how it may be applied in the solution of engineering problems, rather than the mathematical theory of statistics. Margin notes help to guide the student in this interpretation and

understanding. Throughout the book, we provide guidance on how statistical methodology is a key part of the problem-solving process.

Chapter 1 introduces the role of statistics and probability in engineering problem solving. Statistical thinking and the associated methods are illustrated and contrasted with other engineering modeling approaches within the context of the engineering problem-solving method. Highlights of the value of statistical methodologies are discussed using simple examples. Simple summary statistics are introduced.

Chapter 2 illustrates the useful information provided by simple summary and graphical displays. Computer procedures for analyzing large data sets are given. Data analysis methods such as histograms, stem-and-leaf plots, and frequency distributions are illustrated. Using these displays to obtain insight into the behavior of the data or underlying system is emphasized.

Chapter 3 introduces the concepts of a random variable and the probability distribution that describes the behavior of that random variable. We introduce a simple 3-step procedure for structuring a solution to probability problems. We concentrate on the normal distribution, because of its fundamental role in the statistical tools that are frequently applied in engineering. We have tried to avoid using sophisticated mathematics and the event-sample space orientation traditionally used to present this material to engineering students. An in-depth understanding of probability is not necessary to understand how to use statistics for effective engineering problem solving. Other topics in this chapter include expected values, variances, probability plotting, and the central limit theorem.

Chapters 4 and 5 present the basic tools of statistical inference: point estimation, confidence intervals, and hypothesis testing. Techniques for a single sample are in Chapter 4, and two-sample inference techniques are in Chapter 5. Our presentation is distinctly applications oriented and stresses the simple comparative-experiment nature of these procedures. We want engineering students to become interested in how these methods can be used to solve real-world problems and to learn some aspects of the concepts behind them so that they can see how to apply them in other settings. We give a logical, heuristic development of the techniques, rather than a mathematically rigorous one. In this edition, we have focused more extensively on the P -value approach to hypothesis testing because it is relatively easy to understand and is consistent with how modern computer software presents the concepts.

Empirical model building is introduced in *Chapter 6*. Both simple and multiple linear regression models are presented, and the use of these models as approximations to mechanistic models is discussed. We show the student how to find the least squares estimates of the regression coefficients, perform the standard statistical tests and confidence intervals, and use the model residuals for assessing model adequacy. Throughout the chapter, we emphasize the use of the computer for regression model fitting and analysis.

Chapter 7 formally introduces the design of engineering experiments, although much of Chapters 4 and 5 was the foundation for this topic. We emphasize the factorial design and, in particular, the case in which all of the experimental factors are at two levels. Our practical experience indicates that if engineers know how to set up a factorial experiment with all factors at two levels, conduct the experiment properly, and correctly analyze the resulting data, they can successfully attack most of the engineering experiments that they will encounter in the real world. Consequently, we have written this chapter to accomplish these objectives. We also introduce fractional factorial designs and response surface methods.

Statistical quality control is introduced in *Chapter 8*. The important topic of Shewhart control charts is emphasized. The \bar{X} and R charts are presented, along with some simple control charting techniques for individuals and attribute data. We also discuss some aspects of estimating the capability of a process.

The students should be encouraged to work problems to master the subject matter. The book contains an ample number of problems of different levels of difficulty. The end-of-section exercises