STATISTICAL QUALITY CONTROL

A MODERN INTRODUCTION

Douglas C. Montgomery

SIXTH EDITION

INTERNATIONAL STUDENT VERSION

Sixth Edition

Statistical Quality Control: A Modern Introduction

International Student Version

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WILEY

John Wiley & Sons, Inc.

Cover photo: ©istockphoto.com

This book was typeset in 10/12 Times by Aptara, Inc.,

Montgomery, Douglas, C.
Introduction to Statistical Quality Control, Sixth Edition

ISBN: 978-0470-23397-9

Printed in Asia

10 9 8 7 6 5 4 3 2 1

SPC
Calculations for Control Limits

Notation:

- UCL—Upper Control Limit
- LCL—Lower Control Limit
- CL —Center Line
- n —Sample Size
- PCR—Process Capability Ratio
- $\hat{\sigma}$ —Process Standard Deviation
- $\bar{x}$ —Average of Measurements
- $\bar{\bar{x}}$ —Average of Averages
- R —Range
- $\bar{R}$ —Average of Ranges
- USL—Upper Specification Limit
- LSL—Lower Specification Limit

Variables Data ($\bar{x}$ and R Control Charts)

$\bar{x}$ Control Chart

$\text{UCL} = \bar{\bar{x}} + A_2\bar{R}$

$\text{LCL} = \bar{\bar{x}} - A_2\bar{R}$

$\text{CL} = \bar{\bar{x}}$

R Control Chart

$\text{UCL} = \bar{R}\,D_4$

$\text{LCL} = \bar{R}\,D_3$

$\text{CL} = \bar{R}$

Capability Study

$C_p = (\text{USL} - \text{LSL})/(6\,\hat{\sigma})$; where $\hat{\sigma} = \bar{R}/d_2$

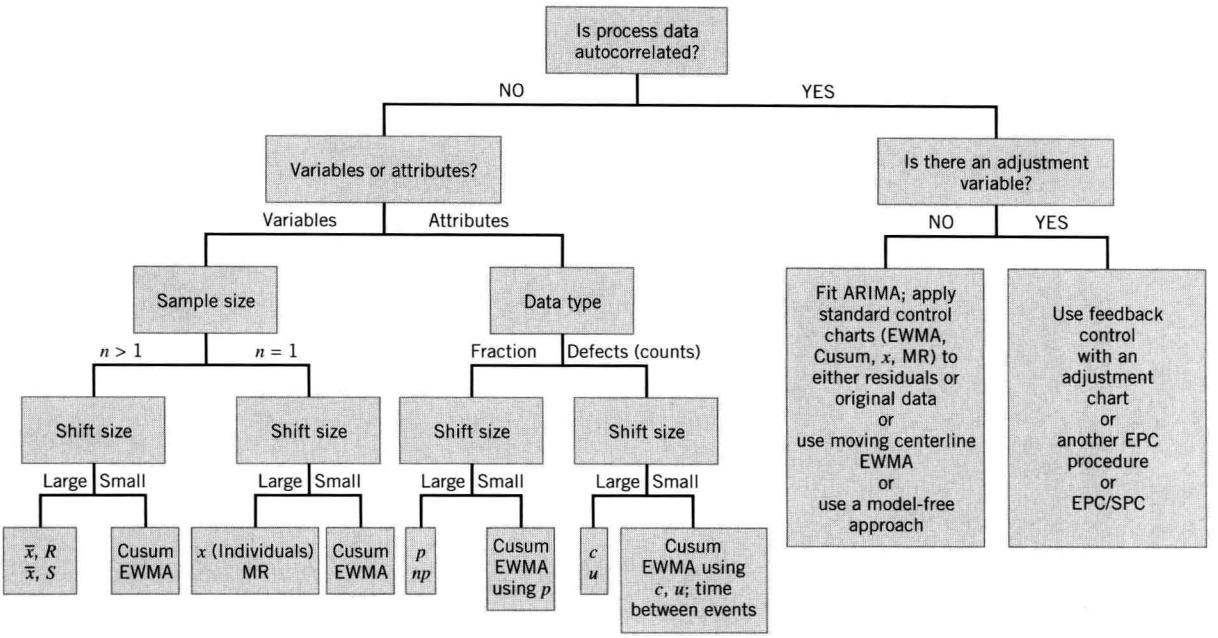
n	A_2	D_3	D_4	d_2
2	1.880	0.000	3.267	1.128
3	1.023	0.000	2.574	1.693
4	0.729	0.000	2.282	2.059
5	0.577	0.000	2.114	2.326
6	0.483	0.000	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078

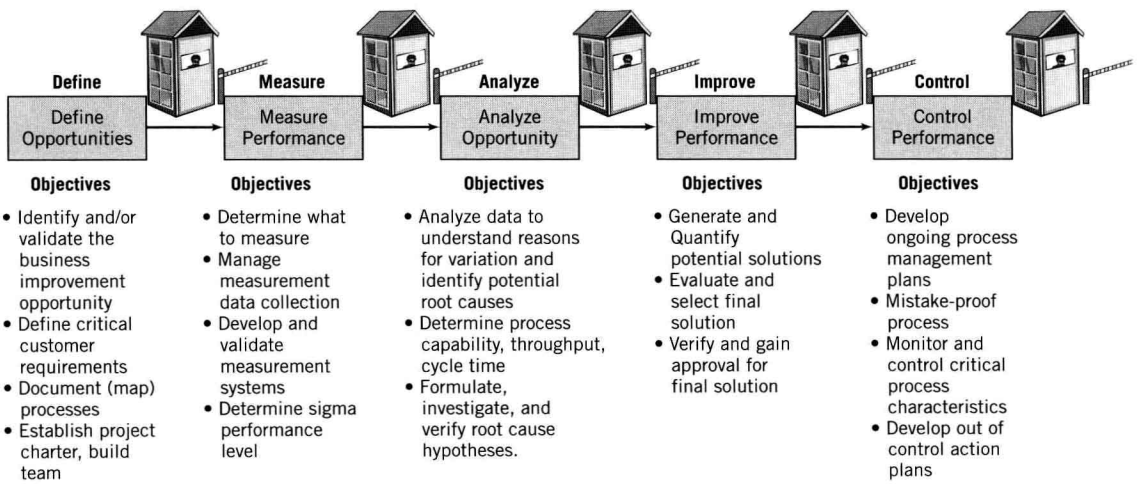
Attribute Data (p, np, c, and u Control Charts)

Control Chart Formulas

	p (fraction)	np (number of nonconforming)	c (count of nonconformances)	u (count of nonconformances/unit)
CL	$\bar{p}$	$n\bar{p}$	$\bar{c}$	$\bar{u}$
UCL	$\bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})}$	$\bar{c} + 3\sqrt{\bar{c}}$	$\bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$
LCL	$\bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$	$n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}$	$\bar{c} - 3\sqrt{\bar{c}}$	$\bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$
Notes	If n varies, use $\bar{n}$ or individual n_i	n must be a constant	n must be a constant	If n varies, use $\bar{n}$ or individual n_i

Guide to Univariate Process Monitoring and Control





The DMAIC Process

About the Author

Douglas C. Montgomery is Regents' Professor of Industrial Engineering and Statistics and the Arizona State University Foundation Professor of Engineering. He received his B.S., M.S., and Ph.D. degrees from Virginia Polytechnic Institute, all in engineering. From 1969 to 1984 he was a faculty member of the School of Industrial & Systems Engineering at the Georgia Institute of Technology; from 1984 to 1988 he was at the University of Washington, where he held the John M. Fluke Distinguished Chair of Manufacturing Engineering, was Professor of Mechanical Engineering, and was Director of the Program in Industrial Engineering.

Dr. Montgomery has research and teaching interests in engineering statistics including statistical quality-control techniques, design of experiments, regression analysis and empirical model building, and the application of operations research methodology to problems in manufacturing systems. He has authored and coauthored more than 190 technical papers in these fields and is the author of twelve other books. Dr. Montgomery is a Fellow of the American Society for Quality, a Fellow of the American Statistical Association, a Fellow of the Royal Statistical Society, a Fellow of the Institute of Industrial Engineers, an elected member of the International Statistical Institute, and an elected Academican of the International Academy of Quality. He is a Shewhart Medalist of the American Society for Quality, and he also has received the Brumbaugh Award, the Lloyd S. Nelson Award, the William G. Hunter Award, and two Shewell Awards from the ASQ. He is a recipient of the Ellis R. Ott Award. He is a former editor of the *Journal of Quality Technology,* is one of the current chief editors of *Quality and Reliability Engineering International,* and serves on the editorial boards of several journals.

Preface

Introduction

This book is about the use of modern statistical methods for quality control and improvement. It provides comprehensive coverage of the subject from basic principles to state-of-the-art concepts and applications. The objective is to give the reader a sound understanding of the principles and the basis for applying them in a variety of situations. Although statistical techniques are emphasized throughout, the book has a strong engineering and management orientation. Extensive knowledge of statistics is not a prerequisite for using this book. Readers whose background includes a basic course in statistical methods will find much of the material in this book easily accessible.

Audience

The book is an outgrowth of more than 35 years of teaching, research, and consulting in the application of statistical methods for industrial problems. It is designed as a textbook for students enrolled in colleges and universities, who are studying engineering, statistics, management, and related fields and are taking a first course in statistical quality control. The basic quality-control course is often taught at the junior or senior level. All of the standard topics for this course are covered in detail. Some more advanced material is also available in the book, and this could be used with advanced undergraduates who have had some previous exposure to the basics or in a course aimed at graduate students. I have also used the text materials extensively in programs for professional practitioners, including quality and reliability engineers, manufacturing and development engineers, product designers, managers, procurement specialists, marketing personnel, technicians and laboratory analysts, inspectors, and operators. Many professionals have also used the material for self-study.

Chapter Organization and Topical Coverage

The book contains five parts. Part I is introductory. The first chapter is an introduction to the philosophy and basic concepts of quality improvement. It notes that quality has become a major business strategy and that organizations that successfully improve quality can increase their productivity, enhance their market penetration, and achieve greater profitability and a strong competitive advantage. Some of the managerial and implementation aspects of quality improvement are included. Chapter 2 describes DMAIC, an acronym for define, measure, analyze, improve, and control. The DMAIC process is an excellent framework to use in conducting quality improvement projects. DMAIC often is associated with six-sigma, but regardless of the approach taken by an organization strategically, DMAIC is an excellent tactical tool for quality professionals to employ.

Part II is a description of statistical methods useful in quality improvement. Topics include sampling and descriptive statistics, the basic notions of probability and probability distributions, point and interval estimation of parameters, and statistical hypothesis testing. These topics are usually covered in a basic course in statistical methods; however, their presentation in this text

is from the quality-engineering viewpoint. My experience has been that even readers with a strong statistical background will find the approach to this material useful and somewhat different from a standard statistics textbook.

Part III contains four chapters covering the basic methods of statistical process control (SPC) and methods for process capability analysis. Even though several SPC problem-solving tools are discussed (including Pareto charts and cause-and-effect diagrams, for example), the primary focus in this section is on the Shewhart control chart. The Shewhart control chart certainly is not new, but its use in modern-day business and industry is of tremendous value.

There are four chapters in Part IV that present more advanced SPC methods. Included are the cumulative sum and exponentially weighted moving average control charts (Chapter 9), several important univariate control charts such as procedures for short production runs, autocorrelated data, and multiple stream processes (Chapter 10), multivariate process monitoring and control (Chapter 11), and feedback adjustment techniques (Chapter 12). Some of this material is at a higher level than Part III, but much of it is accessible by advanced undergraduates or first-year graduate students. This material forms the basis of a second course in statistical quality control and improvement for this audience.

Part V contains two chapters that show how statistically designed experiments can be used for process design, development, and improvement. Chapter 13 presents the fundamental concepts of designed experiments and introduces factorial and fractional factorial designs, with particular emphasis on the two-level system of designs. These designs are used extensively in the industry for factor screening and process characterization. Although the treatment of the subject is not extensive and is no substitute for a formal course in experimental design, it will enable the reader to appreciate more sophisticated examples of experimental design. Chapter 14 introduces response surface methods and designs, illustrates evolutionary operation (EVOP) for process monitoring, and shows how statistically designed experiments can be used for process robustness studies. Chapters 13 and 14 emphasize the important interrelationship between statistical process control and experimental design for process improvement.

Two chapters deal with acceptance sampling in Part VI. The focus is on lot-by-lot acceptance sampling, although there is some discussion of continuous sampling and MIL STD 1235C in Chapter 14. Other sampling topics presented include various aspects of the design of acceptance-sampling plans, a discussion of MIL STD 105E, MIL STD 414 (and their civilian counterparts, ANSI/ASQC ZI.4 and ANSI/ASQC ZI.9), and other techniques such as chain sampling and skip-lot sampling.

Throughout the book, guidelines are given for selecting the proper type of statistical technique to use in a wide variety of situations. Additionally, extensive references to journal articles and other technical literature should assist the reader in applying the methods described. I also have showed how the different techniques presented are used in the DMAIC process.

Supporting Text Materials

Supplemental Text Material

I have written a set of supplemental materials to augment many of the chapters in the book. The supplemental material contains topics that could not easily fit into a chapter without seriously disrupting the flow. The topics are shown in the Table of Contents for the book and in the individual chapter outlines. Some of this material consists of proofs or derivations, new topics of a (sometimes) more advanced nature, supporting details concerning remarks or concepts presented in the text, and answers to frequently asked questions. The supplemental material provides an interesting set of accompanying readings for anyone curious about the field. It is available at www.wiley.com/college/montgomery

Instructor's Materials

The instructor's section of the textbook Web site contains the following:

1. Solutions to the text problems
2. The supplemental text material described above
3. A set of Microsoft® PowerPoint® slides for the basic SPC course
4. Data sets from the book, in electronic form
5. Image Gallery, illustrations from the book in electronic format

The instructor's section is for instructor use only and is password-protected. Visit the Instructor Companion Site portion of the Web site by going to www.wiley.com or call your Wiley representative to register for a password.

The World Wide Web Page

The Web page for the book is accessible through the Wiley home page. It contains the supplemental text material and the data sets in electronic form. It will also be used to post items of interest to text users. Go to www.wiley.com.

ACKNOWLEDGMENTS

Many people have generously contributed their time and knowledge of statistics and quality improvement to this book. I would like to thank Dr. Bill Woodall, Dr. Doug Hawkins, Dr. Joe Sullivan, Dr. George Runger, Dr. Bert Keats, Dr. Bob Hogg, Mr. Eric Ziegel, Dr. Joe Pignatiello, Dr. John Ramberg, Dr. Ernie Saniga, Dr. Enrique Del Castillo, Dr. Sarah Streett, and Dr. Jim Alloway for their thorough and insightful comments on this and previous editions. They generously shared many of their ideas and teaching experiences with me, leading to substantial improvements in the book.

Over the years since the first edition was published, I have received assistance and ideas from a great many other people. A complete list of colleagues with whom I have interacted would be impossible to enumerate. However, some of the major contributors and their professional affiliations are as follows: Dr. Mary R. Anderson-Rowland, Dr. Dwayne A. Rollier, Dr. Norma F. Hubele, and Dr. Murat Kulahci, Arizona State University; Mr. Seymour M. Selig, formerly of the Office of Naval Research; Dr. Lynwood A. Johnson, Dr. Russell G. Heikes, Dr. David E. Fyffe, and Dr. H. M. Wadsworth, Jr., Georgia Institute of Technology; Dr. Sharad Prabhu and Dr. Robert Rodriguez, SAS Institute; Dr. Scott Kowalski, Minitab; Dr. Richard L. Storch and Dr. Christina M. Mastrangelo, University of Washington; Dr. Cynthia A. Lowry, formerly of Texas Christian University; Dr. Smiley Cheng, Dr. John Brewster, Dr. Brian Macpherson, and Dr. Fred Spiring, the University of Manitoba; Dr. Joseph D. Moder, University of Miami; Dr. Frank B. Alt, University of Maryland; Dr. Kenneth E. Case, Oklahoma State University; Dr. Daniel R. McCarville, Dr. Lisa Custer, Dr. Pat Spagon, and Mr. Robert Stuart, all formerly of Motorola; Dr. Richard Post, Intel Corporation; Dr. Dale Sevier, San Diego State University; Mr. John A. Butora, Mr. Leon V. Mason, Mr. Lloyd K. Collins, Mr. Dana D. Lesher, Mr. Roy E. Dent, Mr. Mark Fazey, Ms. Kathy Schuster, Mr. Dan Fritze, Dr. J. S. Gardiner, Mr. Ariel Rosentrater, Mr. Lolly Marwah, Mr. Ed Schleicher, Mr. Amiin Weiner, and Ms. Elaine Baechtle, IBM; Mr. Thomas C. Bingham, Mr. K. Dick Vaughn, Mr. Robert LeDoux, Mr. John Black, Mr. Jack Wires, Dr. Julian Anderson, Mr. Richard Alkire, and Mr. Chase Nielsen, the Boeing Company; Ms. Karen Madison, Mr. Don Walton, and Mr. Mike Goza, Alcoa; Mr. Harry Peterson-Nedry, Ridgecrest Vineyards and The Chehalem Group; Dr. Russell A. Boyles, formerly of Precision Castparts Corporation; Dr. Sadre Khalessi and Mr. Franz Wagner, Signetics Corporation;

Mr. Larry Newton and Mr. C. T. Howlett, Georgia Pacific Corporation; Mr. Robert V. Baxley, Monsanto Chemicals; Dr. Craig Fox, Dr. Thomas L. Sadosky, Mr. James F. Walker, and Mr. John Belvins, the Coca-Cola Company; Mr. Bill Wagner and Mr. Al Pariseau, Litton Industries; Mr. John M. Fluke, Jr., John Fluke Manufacturing Company; Dr. Paul Tobias, formerly of IBM and Semitech; Dr. William DuMouchel and Ms. Janet Olson, BBN Software Products Corporation. I would also like to acknowledge the many contributions of my late partner in Statistical Productivity Consultants, Mr. Sumner S. Averett. All of these individuals and many others have contributed to my knowledge of the quality improvement field.

Other acknowledgments go to the editorial and production staff at Wiley, particularly Ms. Charity Robey and Mr. Wayne Anderson, with whom I worked for many years, and Ms. Jenny Welter; they have had much patience with me over the years and have contributed greatly toward the success of this book. Dr. Cheryl L. Jennings made many valuable contributions by her careful checking of the manuscript and proof materials. I also thank Dr. Gary Hogg and Dr. Ron Askin, former and current chairs of the Department of Industrial Engineering at Arizona State University, for their support and for providing a terrific environment in which to teach and conduct research.

I thank the various professional societies and publishers who have given permission to reproduce their materials in my text. Permission credit is acknowledged at appropriate places in this book.

I am also indebted to the many organizations that have sponsored my research and my graduate students for a number of years, including the member companies of the National Science Foundation/Industry/University Cooperative Research Center in Quality and Reliability Engineering at Arizona State University, the Office of Naval Research, the National Science Foundation, the Semiconductor Research Corporation, the Aluminum Company of America, and the IBM Corporation. Finally, I would like to thank the many users of the previous editions of this book, including students, practicing professionals, and my academic colleagues. Many of the changes and improvements in this edition of the book are the direct result of your feedback.

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Contents

PART 1

Introduction

Controlling and improving quality has become an important business strategy for many organizations; manufacturers, distributors, transportation companies, financial services organizations; health care providers, and government agencies. Quality is a competitive advantage. A business that can delight customers by improving and controlling quality can dominate its competitors. This book is about the technical methods for achieving success in quality control and improvement, and offers guidance on how to successfully implement these methods.

Part 1 contains two chapters. Chapter 1 contains the basic definitions of quality and quality improvement, provides a brief overview of the tools and methods discussed in greater detail in subsequent parts of the book, and discusses the management systems for quality improvement. Chapter 2 is devoted to the DMAIC (define, measure, analyze, improve, and control) problem-solving process, which is an excellent framework for implementing quality improvement. We also show how the methods discussed in the book are used in DMAIC.