

# Statistical Process Control and Quality Improvement

Fifth Edition



Gerald M. Smith

# CONTENTS

## Preface

xiii

## 1 Introduction to Quality Concepts and Statistical Process Control

1

- 1.1 What Is Quality? 1
- 1.2 Definitions of Quality 3
- 1.3 The Need for SPC 4
- 1.4 Prevention Versus Detection 5
- 1.5 SPC Goals 8
- 1.6 The Basic Tools for SPC 9
- 1.7 Statistical Process Control Techniques 9
- 1.8 Applying SPC to an Existing Manufacturing Process 11
- 1.9 Designed Experiments 13
- 1.10 The Quality Toolbox 14

## 2 Striving for Quality: Management's Problem and Management's Solution

17

- 2.1 Management's Problem 17
- 2.2 Management's Dilemma 18

2.3	Leadership by Management	19
2.4	Deming's Contribution to Quality	20
2.5	Deming's 14 Points for Management	22
2.6	Deming's Seven Deadly Diseases	28
2.7	Crosby's Approach	29
	Symptoms of Trouble	30
	Crosby's Four Absolutes of Quality	31
	Crosby's 14 Steps to Quality Improvement	32
2.8	A Comparison of Deming's 14 Points and Crosby's 14 Steps	34
2.9	Which Way to Top Quality?	34
2.10	Pitfalls in the Quest for Quality	36
2.11	Total Quality Management (TQM)	37
2.12	The Malcolm Baldrige National Quality Award	39
2.13	Total Customer Satisfaction	41
2.14	ISO-9000	43
2.15	The Service Sector	45

### **3 Introduction to Variation and Statistics** **47**

3.1	Measurement Concepts	47
	Measurement Error	48
	Round-off Rules	49
3.2	Special-Cause and Common-Cause Variation	51
3.3	The Variation Concepts	52
3.4	Distributions and SPC Goals	55
3.5	Basic Statistical Concepts	57
	Data Collection	60
	Data Organization	61
	Measures of the Center of a Distribution	61
	Measures of the Spread	68
3.6	Distributions and 3 Standard Deviations	74
	The Histogram	77

<b>4</b>	<b>Organization of Data: Introduction to Tables, Charts, and Graphs</b>	<b>83</b>
4.1	Stemplots 83	
4.2	Frequency Distributions and Tally Charts 87	
4.3	Histograms 94	
	Histogram Analysis Examples: Shape Interpretation 98	
4.4	Pareto Charts 102	
4.5	Flowcharts 106	
4.6	Storyboards 111	
4.7	The Cause-and-Effect Diagram 112	
4.8	Checksheets 116	
4.9	Scatterplots 116	
<b>5</b>	<b>Introduction to Probability and the Normal Probability Distribution</b>	<b>129</b>
5.1	Probability 129	
5.2	Compound Probability 131	
	The "Or" Probability 131	
	"And" Probabilities 134	
	Adjusting the "And" Rule 136	
5.3	Counting with Permutations and Combinations 137	
	The Number of Ways 137	
	Permutations, $P_{N,n}$ 138	
	Factorials 139	
	The <i>Mississippi</i> Problem 140	
	The Two-Letter Word Problem 141	
	Combinations 143	
5.4	The Binomial Probability Distribution 145	
	The Simple Random Sample 149	

- 5.5 The Hypergeometric Probability Distribution 149
- 5.6 Probability Distributions 153
- 5.7 The Normal Probability Distribution 158
  - Area Under a Normal Curve 162
  - Other Normal Curve Tables 167
- 5.8 The Application of the Central Limit Theorem 180

## **6 Introduction to Control Charts 189**

- 6.1 The Control Chart Concept 189
  - Variables and Attributes 190
- 6.2 Preparation for Control Charting 193
  - Management Direction 193
  - Planning 193
  - Chart Commentary 193
  - Gauge Capability 194
  - Sampling Plan Preparation 194
- 6.3 Control Charts and Run Charts 196
  - The Run Chart 196
- 6.4 The Basic  $\bar{x}$  and  $R$  Chart 197
- 6.5 The  $\bar{x}$  and  $R$  Chart Procedure 210
  - Action Procedures 216
- 6.6 The Continuation Control Chart 228
- 6.7 The Capability Analysis 229
  - Calculating the Capability Ratio 235
  - The Capability Index 236
- 6.8 Six Sigma 253

## **7 Additional Control Charts for Variables 263**

- 7.1 The Median and Range Chart ( $\tilde{x}$  and  $R$ ) 263
  - The  $\tilde{x}$  and  $R$  Chart Procedure 263
- 7.2 The  $\bar{x}$  and  $s$  Chart 279
- 7.3 Coding Data 292
- 7.4 A Modified  $\bar{x}$  and  $R$  Chart for Small Sets of Data 303

- 7.5 The Nominal  $\bar{x}$  and  $R$  Chart 306
- 7.6 The Transformation  $\bar{x}$  and  $R$  Chart 311
  - The Transformation Formulas 311
  - The Transformation  $\bar{x}$  and  $R$  Procedure 312
  - Chart Analysis 315
- 7.7 Control Chart Selection 316

## **8 Variables Charts for Limited Data 327**

- 8.1 Precontrol or Rainbow Charts 328
  - The Precontrol Procedure 328
  - Calculating Zones 329
- 8.2 A Compound Probability Application 332
- 8.3 Modified Precontrol for Tight Control 333
- 8.4 Charts for Individual Measurements 339
  - The Run Chart 339
  - The  $x$  and  $MR$  Chart 340
  - Procedure for the Individual and Moving Range Chart 341

## **9 Attributes Control Charts 361**

- 9.1 The Four Types of Attributes Charts 362
  - The  $p$  Chart 362
  - The  $np$  Chart 362
  - The  $c$  Chart 362
  - The  $u$  Chart 362
  - Applications of the Charts 362
- 9.2 The  $p$  Chart 363
  - Preparation for the  $p$  Chart 363
  - The  $p$  Chart Procedure 364
- 9.3 The  $np$  Chart 374
- 9.4 The  $c$  Chart 379
- 9.5 The  $u$  Chart 383
- 9.6 SPC Applied to the Learning Process 387
- 9.7 Technology in SPC 390

<b>10</b>			
<b>Interpreting Control Charts</b>			<b>397</b>
10.1	The Random Distribution of Points	399	
10.2	Freaks	400	
10.3	Binomial Distribution Applications	403	
10.4	Freak Patterns	408	
10.5	Shifts	413	
10.6	Runs and Trends	418	
10.7	Time and Control Chart Patterns	422	
10.8	Cycles	423	
10.9	Grouping	425	
10.10	Instability	428	
10.11	Stable Mixtures	429	
10.12	Stratification	430	
10.13	Using Control Chart Patterns in Problem Solving	436	
<b>11</b>			
<b>Problem Solving</b>			<b>443</b>
11.1	The Problem-Solving Sequence	443	
11.2	Teamwork for Problem Solving	445	
11.3	Brainstorming	448	
11.4	Using Problem-Solving Tools	450	
	Histograms for Problem Solving	451	
	Verifying Vendor Quality	460	
11.5	Mistake Proofing	474	
11.6	Problem Solving in Management	476	
11.7	JIT (Just-in-Time)	479	
11.8	Problem Solving in the Classroom	480	
<b>12</b>			
<b>Gauge Capability</b>			<b>485</b>
12.1	Preparations for a Gauge Capability Study	487	
12.2	The Gauge Capability Procedure	487	
12.3	Analysis of R and R with Accuracy and Stability: Maximum Possible Deflection	501	

- 12.4 The Elimination of Gauge Variation from Process Variation 506
- 12.5 Indecisive Gauge Readings 509

## 13

### Acceptance Sampling

513

- 13.1 The Sampling Dilemma 514
- 13.2 Random Sampling 521
- 13.3 Operating Characteristic Curves 522
  - Selecting the Best OC Curve 532
  - Selecting the AQL 533
- 13.4 The Average Outgoing Quality Curve 534
- 13.5 MLT-STD-105D for Inspection by Attributes 537
- 13.6 The Average Proportion Defective 550
- 13.7 Vendor Certification and Control Chart Monitoring 555

## A

### Basic Math Concepts and Probability

557

- A.1 Signed Numbers 557
  - Operations with Signed Numbers 558
  - Addition Rules 558
  - Subtraction 560
  - Multiplication and Division 561
- A.2 Variables 562
  - Operations 563
  - Addition 563
  - Subtraction 563
  - Multiplication 564
  - Division 564
  - Powers 564
  - Roots 566
- A.3 Order of Operations 567
- A.4 Inequalities 569
- A.5 Using the Statistical Calculator 571



<b>B</b>		
<b>Charts and Tables</b>		<b>573</b>
B.1	Formulas and Constants for Control Charts	573
	Average and Range Charts: $\bar{x}$ and $R$	573
	Median and Range Charts: $\tilde{x}$ and $R$	574
	Average and Standard Deviation: $\bar{x}$ and $s$	575
	Individual Measurement and Moving Range: $x$ and $MR$	575
	Attributes Charts	576
B.2	The $G$ Chart	579
B.3	The Normal Distribution Table (Tail Area)	580
B.4	The Normal Distribution Table (Center Area)	582
B.5	The Normal Distribution Table (Left Area)	584
B.6	Process Capability	586
<b>C</b>		
<b>Glossary of Symbols</b>		<b>587</b>
<b>D</b>		
<b>Lab Exercises</b>		<b>589</b>
<b>Answers to Exercises</b>		<b>605</b>
<b>Index</b>		<b>647</b>